AD-A062 432 CIVIL ENGINEERING LAB (NAVY) PORT HUENEME CALIF F/G 13/2

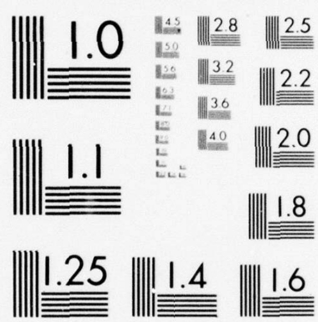
AN ASSESSMENT OF TRANSPORTABLE BREAKWATERS WITH REFERENCE TO TH--ETC(U)

SEP 78 D B JONES

UNCLASSIFIED CEL-TN-1529 NL

1 OF 2

AD
A062432


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3

LEVEL II

(12)
NW

Technical Note

CEL

TN no. N-1529

title: AN ASSESSMENT OF TRANSPORTABLE BREAKWATERS WITH REFERENCE TO THE CONTAINER OFF-LOADING AND TRANSFER SYSTEM (COTS)

author: D. B. Jones

date: September 1978

sponsor: Naval Facilities Engineering Command

program nos: YF53.536.091.01.002A

DEPARTMENT OF THE NAVY
CIVIL ENGINEERING LABORATORY

CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

Approved for public release; distribution unlimited.

CONVERSION OF UNITS

1 foot (ft)	= 0.3048 meter (m)
1 inch (in.)	= 0.0254 meter (m)
1 knot (kt)	= 0.515 meter/second (m/s)
1 pound (lb)	= 4.448 Newtons (N)
1 ton (T)	= 0.9072 tonnes (t)
1 long ton (LT)	= 1.016 tonnes (t)
1 horsepower (hp)	= 0.7457 kilowatts (kW)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TN-1529	2. GOVT ACCESSION NO. DN787093	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) AN ASSESSMENT OF TRANSPORTABLE BREAKWATERS WITH REFERENCE TO THE CONTAINER OFF-LOADING AND TRANSFER SYSTEM (COTS).		5. TYPE OF REPORT & PERIOD COVERED Final; Feb 1977 – Jan 1978 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) D. B. Jones		8. CONTRACT OR GRANT NUMBER(s) (12) 119 p.
9. PERFORMING ORGANIZATION NAME AND ADDRESS CIVIL ENGINEERING LABORATORY Naval Construction Battalion Center Port Hueneme, California 93043		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62760N; YF53.536.091.01.002A
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Facilities Engineering Command Alexandria, Virginia 22332		12. REPORT DATE (11) September 1978 13. NUMBER OF PAGES 100
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (14) CEL-TN-1529		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(9) Final rept. Feb 77–Jan 78,

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(16) F53536

(17) YF53536091

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Breakwaters, transportable breakwaters, tethered float breakwater, sloping float breakwater, inclined pontoon breakwater, ship-transport, logistic burden.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study covering three specific designs for a tethered float breakwater and simple and legged versions of the sloping float (inclined pontoon) breakwater has resulted in improved definition of certain aspects of the logistic burden connected with transportable breakwaters in military operations. Performance data reported for the two types were analyzed in order to determine the transverse cross-section dimensions required for 50% reduction of the significant wave height associated with the Pierson-Moskowitz wave spectrum with (continued)

CONT

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

391 111

CONT'

20. Continued

7-second peak period. Specific designs with this capability were then examined to assess requirements for overseas transportation, installation, and cost. The stated performance requirement was drawn from an analysis of the Container Off-Loading and Transfer System (COTS). This analysis concluded that wave-induced motions of moored lighters, barges, and floating platforms (with natural periods between 2 and 7 seconds) could adversely affect cargo flow rates. Thus, a breakwater effective for 7-second waves could decrease the frequency and duration of occasions when the system is degraded by wave action. Bargeships, ships with well decks, or large ocean-going barges would be required to transport the modules of the various designs for a 7-second breakwater. A LASH bargeship is the most likely carrier for COTS breakwaters. LASH capacity varies from 750 to 3,600 lineal feet of breakwater, depending upon the particular vessel and the breakwater design. For the various points in the COTS where a breakwater would be beneficial, the length of breakwater required varies from 650 to 4,000 feet.

Library Card

Civil Engineering Laboratory
AN ASSESSMENT OF TRANSPORTABLE BREAKWATERS WITH REFERENCE TO THE CONTAINER OFF-LOADING AND TRANSFER SYSTEM (COTS) (Final), by D. B. Jones
TN-1529 100 pp illus September 1978 Unclassified

1. Transportable breakwaters 2. Logistic burden I. YF53.536.091.01.002A

A study covering three specific designs for a tethered float breakwater and simple and legged versions of the sloping float breakwater has resulted in improved definition of the logistic burden of transportable breakwaters in military operations. Performance data reported for the two types were analyzed in order to determine the transverse cross-section dimensions required for 50% reduction of the significant wave height associated with the Pierson-Moskowitz wave spectrum with 7-second peak period. Specific designs with this capability were then examined to assess requirements for overseas transportation, installation, and cost. The stated performance requirement was drawn from an analysis of the Container Off-Loading and Transfer System (COTS). This analysis concluded that wave-induced motions of moored lighters, barges, and floating platforms (with natural periods between 2 and 7 seconds) could adversely affect cargo flow rates. Thus, a breakwater effective for 7-second waves could decrease the frequency and duration of occasions when the system is degraded by wave action. Bargeships, ships with well decks, or large ocean-going barges would be required to transport the modules of the various designs for a 7-second breakwater. A LASH bargeship is the most likely carrier for COTS breakwaters. LASH capacity varies from 750 to 3,600 lineal feet of breakwater.

CONTENTS

Page

LIST OF ILLUSTRATIONS

Page

Page

LIST OF TABLES

SYNOPSIS

Wave Attenuation Needs in COTS Operations

Most of the schemes for transferring containers and other cargo from containerships, bargeships, and Roll-On/Roll-Off (RO/RO) ships anchored offshore to points on an adjacent beach involve small, moored platforms or vessels. Most of these small floating structures are pivotal points in the cargo flow process; slowdown or interruption of operations at these points would lower the daily throughput. Operations at these points are particularly vulnerable because of the responsiveness of small floating structures to ocean waves. Therefore, it is reasonable to expect that wave protection for these structures would decrease the frequency and duration of periods when cargo flow is slowed or even halted because of excessive motion of the structure.

The following specific cargo transfer operations have been under consideration:

- Transfer of containers from a moored containership or bargeship to lighters* by a crane on the deck of the ship or on the deck of an adjacent ship, referred to as a large TCDF (Temporary Container Discharge Facility).
- Transfer of containers from a moored containership or bargeship to lighters by a crane on a barge such as the DeLong "B" barge, referred to as a small TCDF.
- Transfer of containers on vehicles from a moored RO/RO ship to a causeway ferry via an interface platform.
- Unstuffing of barges and transfer of cargo to lighters by a crane mounted on a floating platform, referred to as a cargo discharge facility.
- Transfer of cargo from LCU's and other lighters to trucks on the elevated causeway by a crane on the causeway.

The cargo transfer system is to function at full capacity when sea states are 3 or less, that is, when the significant height of the incident waves varies up to 5 or 6 feet (maximum wave heights up to 10 or 12 feet) and the dominant wave period varies up to 6 or 7 seconds. For excitation periods less than 6 or 7 seconds, response amplitude operators for the small floating components of the COTS reach peak values, but the motions

*LCU, LCM-8, LARC-60, LACV-30, causeway ferry.

of the cargo ships are still quite small. A breakwater which is effective for wave periods only up to about 7 seconds would nevertheless result in reduced motion of the small hulls; therefore, it would enhance operations whenever wave heights are great enough to be troublesome and, simultaneously, the dominant wave period is less than about 7 seconds.

A somewhat different application is that of wave protection for cargo barges, e.g., LASH barges stored (moored) in a barge marshalling area. The perceived need is to safeguard moored barges against damage or loss and to maintain safety and efficiency during the maneuvering and mooring of barges. The breakwater performance requirement in this application, in terms of the wave period for which significant effectiveness is mandatory, is not defined. However, effectiveness for wave periods up to 7 seconds is expected to be beneficial in view of the size of these barges.

A breakwater for such applications as these must be transportable. For contingency operations, it should be ship-transportable and readily installable without use of resources that might be available on the land adjacent. The axial length of the breakwater and the depth of water for which it is designed depend upon the particular application.

Seven-Second Breakwaters

By definition adopted for this study, a "7-second breakwater" is one which produces 50% reduction of the significant wave height in a storm sea represented by the Pierson-Moskowitz wave spectrum with 7-second peak period. Since the significant wave height for this spectrum is 6.4 feet, the significant wave height in the lee of the breakwater would be 3.2 feet (within the sea state 3 range). It is characteristic of partial wave barriers that the reduction of wave height is somewhat less than 50% if the incident wave spectrum is more sharply peaked than the Pierson-Moskowitz spectrum (as, for example, in fetch-limited cases represented by a JONSWAP spectrum) and more than 50% when significant energy exists over a broader range of wave frequencies than that covered by a Pierson-Moskowitz spectrum (as when another wave system with lower, longer waves is superimposed on the storm waves). It is also characteristic that the degree of wave height reduction decreases as the dominant period of the incident waves increases, and conversely. Evidence of this property can be seen in Table I, which summarizes performance for the 7-second breakwaters examined in this study.

Performance and logistic analyses were made for six designs for a 7-second breakwater, covering both deep and shallow water, which are particular realizations of two breakwater concepts under investigation – the tethered float and the sloping float. The six designs are as follows (see Figure I):

- Design T1: A floating tethered float breakwater with 65-cu ft spherical floats of rigid plastic and a concrete-box ballast.
- Design T2: A floating tethered float breakwater with 65-cu ft spherical floats of rigid plastic and an articulated-frame ballast of concrete.

- Design T3: A bottom-resting tethered float breakwater with 13-cu ft cylindrical floats, constructed from tire casings, and a steel-frame ballast.
- Design S1: A sloping float breakwater adapted from 3x15 (21 by 90-foot) Navy Lightered (NL) P-series pontoon barges or causeway sections.
- Design S2: A sloping float breakwater composed of 28 by 90-foot floats (P-series pontoons or other construction) with 30-foot legs.
- Design S3: A sloping float breakwater composed of 28 by 120-foot floats (P-series pontoons or other construction) with 40-foot legs.

Table I. Effect of a 7-Second Breakwater

Dominant Wave Period (sec)	Sea State	Incident Waves[a]		Transmitted Waves[b]	
		Significant Height[c] (ft)	Maximum Height (ft)	Significant Height (ft)	Maximum Height (ft)
8	5-	8.3	16	5.3	10
7	4	6.4	12	3.2	6
6	3	4.7	9	1.5	3
5	3-	3.3	6	0.6	1

[a]Pierson-Moskowitz spectrum for fully developed sea.

[b]Approximation for legless sloping float breakwaters in shallow water (design S1) and for deep-water tethered float breakwaters (designs T1 and T2).

[c]Exceeded by 13% of the waves.

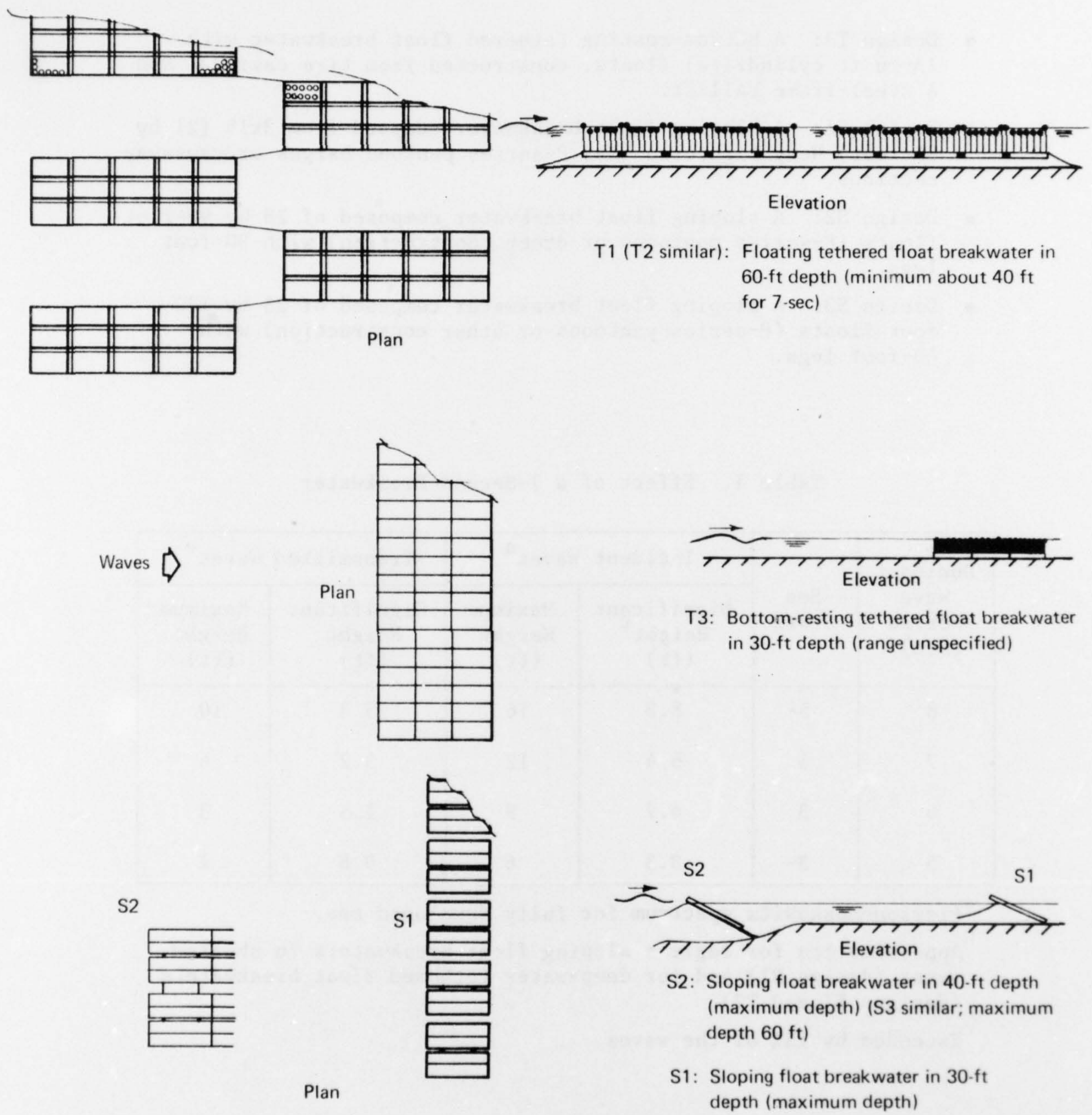


Figure I. Configurations of breakwaters under study.

Findings

Properties of 7-Second Breakwaters for Various COTS Applications. The analyses showed that no one breakwater design among those considered can satisfy all the needs in COTS for a 7-second breakwater because of limits on the depth of water in which the various breakwaters can be installed together with restrictions on the location of some of the COTS components. Table II shows which designs are applicable in various circumstances and summarizes properties of the various installations. A breakwater for a barge marshalling area is included as a footnote to the table; at this time the required length is not well-defined.

Transportability of 7-Second Breakwaters. Bargeships, ships with well decks, or large ocean-going barges are required to carry the various breakwater modules. Consideration of the probable availability of various ships and of desirable transport speeds indicates that only the LASH is feasible for overseas transport of the breakwater modules. Table III shows the estimated space available on a LASH, expressed as the total axial length of a ribbon-type breakwater. Design T2 is omitted because components can be carried on a LASH only in the unassembled condition and assembly time at the destination is considered excessive. Design T3 is omitted from Table III because performance data which form part of the basis for the figures in Column 2 have not been reported.

Summarizing Discussion

For the ship unloading area, the floating tethered float breakwater appears to be the most suitable design among those considered, and only this design is included in Section 1 of Table II. None of the sloping float designs can be used in depths greater than 60 feet, yet the depth at the breakwater would be at least 50 feet and could easily exceed 60 feet. A bottom-resting tethered float breakwater seems less suitable here than a floating version because of greater mass and greater sensitivity to depth, hence greater need for advance information on the site. (Excessive depth of water associated with unanticipated variations in seabed topography or with high tidal elevation can compromise the performance of a bottom-resting system through excessive submergence of the floats.) The minimum length of the breakwater (of design T1) in this application is 1,800 feet. This length pertains to a fixed-heading mooring. It would pertain also to a swing mooring in which the swinging is restricted to a 180-degree arc. In this case, operations on one side of the ship (for example, the side of a RO/RO ship on which the only ports are located) would be sheltered at all times, either by the breakwater or by the ship itself. Complete protection for a 180-degree swing mooring requires 3,000 feet of breakwater. For either complete sheltering or partial sheltering, an additional 1,000 feet of breakwater is required if the ship swings over a 360-degree arc. Table III shows that one large LASH (C9) is required to carry 1,800 feet of breakwater of design T1; these modules are designed for stowage in the hold in the spaces normally occupied by the ship's lighters.

Table II. COTS Breakwater Properties

Conditions	Breakwater Design	Depth at Breakwater		Expanse of Breakwater		Estimated Cost ($M)	Time To Install (days)
		Minimum (ft)	Maximum (ft)	Beam (ft)	Length (ft)		
1. Breakwater for ship anchorage							
Fixed heading							
Perpendicular to breakwater axis	T1	60[a]	b	750	1,800	9.6	8-1/2
Parallel to breakwater axis	T1	60[a]	b	750	1,800	9.6	8-1/2
Swing mooring[c]							
Full protection	T1	60[a]	b	750	3,000	15.9	13
Protection for one side	T1	60[a]	b	750	1,800	9.6	8-1/2
2. Breakwater for cargo discharge facility (barge unstuffing)[d]							
200-ft clearance between breakwater and crane platform	T1	40	b	750	1,070	5.7	5-1/2
	T3	20[a]	b	b	b	b	b
	S3	20[a]	60	160	700	4.7	5
	S2	20[a]	40	120	630	3.4	4
	S1	20[a]	30	90	620	2.1	3
3. Breakwater for elevated causeway							
280-ft clearance between breakwater and end of causeway	T3	20	32[a]	b	b	b	b
	S2	15[a]	32[a]	120	700	3.6	4-1/2
	S1	15[a]	32[a]	90	680	2.2	3

[a]This limit is due to an operating requirement. Otherwise, the indicated minimum or maximum is due to some property of the breakwater.

(continued)

Table II. Continued

[b]No data.

[c]Development of a technique to restrict the swing to 180 degrees is assumed. To accommodate 360-degree swing, the lengths of breakwater would be 4,000 ft (vice 3,000 ft) and 2,800 ft (vice 1,800 ft).

[d]All five designs are also applicable to a breakwater for a barge marshalling area. Data would not differ except that (1) the length of the breakwater for a marshalling area for 80 barges would be 2,500 to 3,500 feet, depending upon the barge mooring layout, (2) costs and installation times would be increased accordingly, and (3) the minimum depth at the breakwater would be greater than indicated to accommodate the sea-to-shore expanse of the marshalling area.

Table III. LASH Transport of 7-Second Breakwaters

Design	Number of Feet of Breakwater Per Ship	Comments
T1	1,200 to 1,900[a]	Modules are carried on the hatch covers and below deck.
S1	750	Modules are carried on the hatch covers.
S2a	1,000	Modules (floats) have retractable legs and are carried on the hatch covers.
S2b	2,300 to 3,600[a]	Modules (floats) have fixed legs and are carried on the hatch covers and below deck.
S3	2,300 to 3,600[a]	The floats have retractable legs. Modules (floats) are carried on the hatch covers and below deck.

[a]The range of values corresponds to the range of capacities of LASH ships.

Wave protection for barge unstuffing operations at a cargo discharge facility can be obtained with any of the five breakwater designs listed in Section 2 of Table II. Certain limitations on the depth of water have been estimated for some of the designs, as noted in Table II, which also shows the length of breakwater required at this facility. Table III shows that transporting these lengths on a LASH requires:

- For design T1, one ship, with modules stowed in the hold.
- For designs S3 and S2b, all of the deck space or one-fourth to one-half of the space in the hold of one ship.
- For design S2a, all of the deck space of one ship.
- For design S1, all of the deck space of one ship.

Designs S2b and S3 are to be designed for stowage in the hold in the spaces normally occupied by the ship's lighters.

A breakwater for a barge marshalling area could utilize any of the five designs just noted. The data in Section 2 of Table II apply, except that the length of breakwater would be greater than the value shown, apparently by a factor of about 3 for design T1 and about 5 for designs S1, S2, and S3. The costs and installation times would be correspondingly increased.

Wave protection for the elevated causeway could be provided by any of the sloping float breakwater designs or by a bottom-resting tethered float breakwater. The performance data needed to evaluate the latter in this application, where the variation of depth can be significant, have not been reported. A breakwater of one of the sloping float designs would be about 700 feet long. Therefore, the space on a LASH required for transporting this breakwater is essentially the same as for a breakwater for a cargo discharge facility; applicable designs are S1, S2a, and S2b.

INTRODUCTION

Operational Requirements*

Logistic support for sustained contingency operations requires, in the absence of developed port facilities, the lightering of containerized cargo from commercial ships anchored offshore to points on an adjacent beach. The area of operations is not necessarily one that is naturally sheltered from high waves, and wave-induced motions of ships and lighters could impede, endanger, and even suspend cargo transfer operations. Thus, the program plan (Ref. 1) for developing a Container Offloading and Transfer System (COTS) includes as an objective the development of wave attenuation equipment. Deployable breakwaters potentially can reduce the motions of moored lighters, barges, and floating platforms, which are responsive to short waves as well as long, and thus can complement motion compensation devices for cranes.

A COTS program requirement is the transport of all elements of the system without placing additional demands on existing Navy amphibious ships and without relying on any one type of shipping (Ref. 1). Thus, adaptability of the wave attenuation system to various modes of transportation is an implied design objective.

Certain other design goals (system properties) are implicit in the nature of the mission. Negligible maintenance during the first year after installation is highly desirable. However, a service life of much more than 1 year is not likely to be required. Fairly rapid installation is implied for any contingency operation; thus, completion of the installation between D+5 and D+20 has been a requirement (Ref. 2).** In a contingency, construction resources will not be available on the land adjacent. Removal of the breakwater from a foreign shore is potentially required and should be considered, although this item may not be of the highest priority. Expeditious retrieval is a potential requirement if, with little advance notice, a breakwater already in use in industry must be commandeered by the military or if the site of a military operation must be moved. Upon retrieval, minimal need for renovation is desirable.

*See Appendix A for background details.

**The precedent set at Normandy in 1944 is noteworthy. The Phoenix caisson breakwater was installed in depths up to 40 to 60 feet at extreme high tide at an average rate of about 500 ft/day and maximum short-term rates of 1,000 to 1,200 ft/day. The Bombardon floating breakwater was installed at an average rate of 1,000 to 1,200 ft/day in water about 100 feet deep at high tide.

Background For The Analysis

Sample Questions and Answers. This study was undertaken to answer questions about the logistics of a transportable wave attenuation system such as the following: What kinds of ships could carry the wave attenuation system (transportable breakwater)? How many ships would be required? What other principal items of equipment and how much time would be required for installation? What is the cost? Answers to such questions must be qualified if they are to be precise. For example, in answer to the first question, the kind of ship required to carry a breakwater varies with the size and form of the largest breakwater component or module. Thus, an answer depends upon the kind of breakwater (structural form) and for each kind upon certain design features.

The number of ships depends upon (1) the axial length of the breakwater and (2) the weight and cube of breakwater material per increment of axial length. The required axial length depends upon the expanse of the area to be sheltered, which in turn depends upon such things as the type of breakwater used and its proximity to the area to be protected. Although breakwater logistic data can be stated in terms of quantities per unit incremental length of breakwater (e.g., number of ships of Type X per 1,000 feet of breakwater of Design Y), the question of the number of increments remains. In COTS operations, there are several separate areas of operation where breakwater protection may be advisable. The length of breakwater required at each area is easier to estimate than total length and is probably the more useful information. The required axial length is dependent upon the type of breakwater and the layout for the particular operating area and could range from 100 to 4,000 feet. The most practical solutions would appear to be in the range from 600 to 1,800 feet. Breakwater requirements at the various areas are considered in fuller detail in the following section.

The weight and volume of a breakwater per increment of axial length depend not only upon the type of breakwater but also upon the required duty of the breakwater. For example, a breakwater that reduces wave height 50% in a sea where the dominant wave period is 7 seconds requires much less material than a breakwater of the same kind which reduces predominantly 7-second waves 90% or one which reduces predominantly 10-second waves 50%. In summary, logistic numbers can be generated once the performance requirement and the performance characteristics are stated.

Derivation of Answers. Answers to the questions posed were reached in the following manner:

1. The required duty of the breakwaters was assumed to be to reduce the significant wave height 50% for a Pierson-Moskowitz spectrum with peak at 7 seconds.* The rationale for choosing this level of breakwater effectiveness is presented in the following section.

*The sea condition is a fully developed sea, as represented by this spectrum, in which spectral components around 7 seconds contain the most energy. For the 7-second spectrum, the significant wave height is 6.4 feet and the maximum wave height expected over many hours is about 12 feet.

2. Two breakwater concepts - the sloping float (Ref. 3) and the tethered float (Ref. 4-6) - were chosen for study on the basis that their wave attenuation properties are well enough known and good enough to merit closer scrutiny. From these concepts, it seemed, specific designs could be developed with the desired durability and with a high potential for rapid overseas transportation and deployment. Few concepts appear to be acceptable on all these counts.

3. The wave attenuation properties were analyzed, and the transverse cross-section dimensions needed to yield the required performance were determined.

4. Three specific conceptual designs for a tethered float breakwater for both deep and shallow water and three designs for a sloping float breakwater for generally shallow water were considered. Estimates were made of various properties of logistic significance, such as cost, transportability, and installation requirements.

Status of Transportable Breakwater Development

More than 100 concepts for transportable breakwaters existing in 1970 were reviewed to identify those that would be most suitable for military use (Ref. 7). That study suggested classification according to structural type or form* (see Table 1 for a revised version of the classification). From the study, it was concluded that the most likely choices of transportable breakwaters that are broadly effective** and, therefore, most likely to meet unknown operational requirements were the two classes of full-depth barriers: (1) fixed (bottom-resting) structures and (2) semifloating (bottom-touching) barriers. The Phoenix concrete caisson is typical of the former, and the Patrick sloping float of the latter. Because bottom-resting total barriers tend to be either unstable in extreme wave conditions or else not very mobile (mobility and stability tend to be conflicting goals), it was concluded that semifloating barriers constitute the most promising class of transportable breakwater for exposed ocean locations. Only two such concepts were uncovered in the survey: the sloping float (Ref. 3) and artificial beaches (Ref. 13, 14). The sloping float breakwater (also termed inclined pontoon breakwater) was found to be the more effective of the two, and it appeared to be readily deployable. Moreover, it appears possible to develop a design which is ship-transportable and which can utilize existing amphibious equipment - a feature inherent in the original concept. Of course, the various total-barrier concepts are limited in application to shallow water.

---

*Other classifications have been made (e.g., according to hydrodynamic principle or mechanism); however, classification by structural form has proved to be useful in judging operational feasibility.

**Defined as capable of a significant degree of wave height reduction over a reasonably large part of the range of wave periods to be expected at an exposed seacoast.

Table 1. Breakwater Classification

Classification	Example and Year[a]	Reference No.
Fixed structures (bottom-resting structures)		
Full-depth barriers	Phoenix caisson, 1944	8
Partial barriers	FMC Sea Fence, 1972	9
Moving structures		
Semifloating barriers (bottom-touching structures)		
Full-depth barriers		
Hard barriers	Patrick sloping float, 1951	3
Soft barriers	None	-
Partial barriers		
Hard barriers	Oscillating breakwater, 1948	10
Soft barriers	None	-
Fully-floating barriers (moored floats)		
Full-depth barriers		
Hard barriers	None	-
Soft barriers	None	-
Partial barriers		
Hard barriers		
Large elements	Bombardon cruciform pontoon, 1944	11
Small elements	Tethered spheres, 1974	4
Soft barriers		
Large elements	Cylindrical bags, 1960	12
Small elements	Tethered balloons, 1960	12

[a]Year refers to first notice of each example.

The sloping float concept originated with LT D. A. Patrick, CEC, USN, who tested the theory in a wave-tank at the University of California in 1951 (Ref. 3).* This exploratory research, motivated by a recognition of need for breakwaters in amphibious operations, dealt primarily with concepts suitable for shallow water, particularly those utilizing Navy Lightered (NL) pontoon structures with lengths up to 175 feet, the longest standard pontoon string. The structures tested were not truly models of existing equipment, and the effects on performance of various properties of the breakwater were not fully investigated; therefore, the data on performance were and are regarded as preliminary. However, the results were sufficiently encouraging for Patrick to recommend confirmatory, full-scale operational tests and three-dimensional model tests. After the 1971 survey (Ref. 7) revealed advantageous performance characteristics of the sloping float relative to other existing concepts, the initial steps were taken toward developing a general performance prediction technique. After a hiatus this effort was renewed in 1977.

The tethered float concept** was proposed by Professor John D. Isaacs of the Scripps Institution of Oceanography, San Diego, California, in 1970 (Ref. 15). A research project sponsored by the California Department of Navigation and Ocean Development and the California Sea Grant College Program of the National Oceanic and Atmospheric Administration Sea Grant Program began in 1972. Preliminary performance data were published in 1974 (Ref. 4). Engineering development was undertaken in a joint project of the state of California and the Naval Facilities Engineering Command and continued under the aegis of a consortium of federal and state government agencies, including the Army Corps of Engineers and the Maritime Administration (Ref. 15). In addition, a private contractor performed a market survey for the Maritime Administration to assess the potential for commercial use of this system (Ref. 16). Additional wave-tank testing and tests of a floating "marina-scale" system (12-inch spherical floats) in San Diego Bay were used to develop a prediction technique for wave attenuation by floating systems. A report containing a general performance prediction technique for deep-water systems - floating systems with low-density, spherical floats - has been issued (Ref. 6). Installation of a small ocean-scale system (256 floats displacing 900 pounds each) was accomplished in 1978. This system is a bottom-resting system for shallow water, employing cylindrical floats constructed from automobile tire casings. A report containing a general performance prediction technique for shallow-water systems - cylindrical floats with various densities and tether lengths - has not been issued.

---

*Task supported by the Office of Naval Research and the Bureau of Ships.

**Dissipation of wave energy through forced (wave-induced) oscillations of floats attached to vertical tethers.

WAVE ATTENUATION NEEDS IN COTS OPERATIONS

Cargo Flow

Ways and means proposed for moving cargo from ship to shore are summarized schematically in Figure 1. This diagram shows the various types of merchant vessel on which cargo would arrive, the special facilities proposed for transferring the cargo to lighters, and the various kinds of lighter and their discharge points at the shore. The components of the cargo movement system shown in boxes are small, moored platforms or vessels, located as shown in Figure 2. Most of these small floating components are pivotal points in the cargo flow process; slowdown or interruption of operations at these points would lower the daily throughput. Moreover, operations at these points are particularly vulnerable because of the responsiveness of small floating structures to ocean waves. Wave protection at these points would be expected to increase operational safety as well as decrease the frequency and duration of periods when cargo flow is slowed or even halted because of excessive motion of the small floating structures. The following section of the document describes specific areas where cargo transfer operations would be adversely affected by waves and could benefit from installation of a breakwater.

Specific Breakwater Needs

Ship Offloading. Containers would be transferred by cranes located either on the deck of the containership or on a platform alongside the containership, referred to as a Temporary Container Discharge Facility (TCDF). As shown in Figure 2, the TCDF may be another ship or a small floating platform such as the DeLong "B" barge. With the crane mounted on the deck of the cargo vessel or on a large TCDF (ship), container transfer is inhibited by wave-induced relative motion between the crane and the lighter because of the mismatch of hull sizes. In this case, large relative motion for wave periods less than about 7 seconds is due primarily to motion of the smaller hull. With the crane mounted on a small TCDF, the absolute motion of the crane base itself is troublesome. Thus, with either crane location, operations would be improved by stabilizing the motion of the small floating component. A breakwater whose effectiveness extends only up to about 7 seconds would suffice.

RO/RO ships may be unloaded by (1) lowering vehicles over the side with a crane on deck, (2) driving or lifting vehicles onto an adjacent ship (basically a TCDF) and thence onto a lighter by ramp or crane, or (3) driving the laden vehicles down a ramp directly onto the causeway ferry (the most efficient lighter for this service). Problems associated with case 1 are essentially those described for containership offloading. Problems associated with case 2 are essentially included in cases 1 and 3. In case 3 (roll-off discharge), an intermediate transfer platform may be needed between the ramp and the lighter. The platform must be

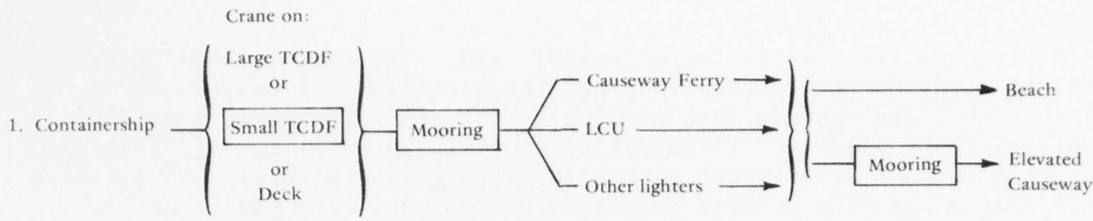
free to move relative to the ship (Ref. 17). Therefore, wave-induced relative motion between the ship and the platform will exist. The ship's hull can provide wave protection for some orientations of the ship, but not all. For illustration of stern-gate offloading, Figure 2 shows a compact arrangement of platform and causeway ferry that utilizes the ship's hull for partial shelter and thus minimizes the expanse of breakwater needed. Side-port offloading, not shown in Figure 2, is even better-suited than stern-gate offloading for use of the ship's wave shadow. In other techniques under consideration, an interface platform is not used. In any case, when the ship swings around and exposes the ramp, interface platform if any, and lighter to waves, a means for reducing motion is probably required even for quite low sea states.

Discharging a bargeship's lighters can take place in moderate waves; however, lost time and extra hazards are associated with tugs maneuvering barges away from the ship's gantry crane. Backloading barges may be more difficult than offloading barges, especially if winches are not used. Apparently, protection even with rather short waves would be beneficial.

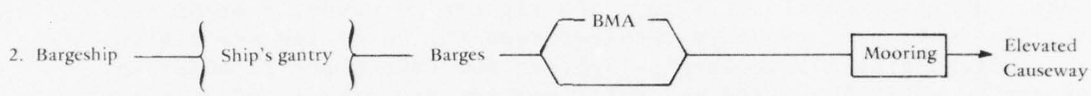
Several plans for wave protection in the area of the ship's anchorage are available for consideration. One is a long breakwater which shelters the entire ship complex. A separate structure that can be left unattended once it is moored would have some advantage. Therefore, this breakwater probably should have its own mooring system. Great length of a breakwater is a logistic disadvantage. The length actually required for this breakwater depends upon the range of headings which the moored ship is permitted to take, as illustrated in Figure 3.

The other extreme is a short breakwater sheltering only a small area around the platform and lighters. The logistic advantage inherent in shortness can be realized if the breakwater can be brought close to the area to be sheltered. For example, a short wing-wall or spur-wall floated into a position adjacent to the large ship's hull need be only 100 to 150 feet long. A means of holding it in position would have to be devised. Possibly, for the wave periods of interest, wave loads would be too great to contend with. A significant disadvantage is that the design must be adaptable to various ships and to various positions along the hull, including the stern. For this option, time would be required to position and secure the breakwater each time a ship arrived. With a 100-foot wing-wall, the range of ship headings for which a TCDF is sheltered would probably be no more than 45 degrees larger than the range when only the ship's hull is the wave barrier.

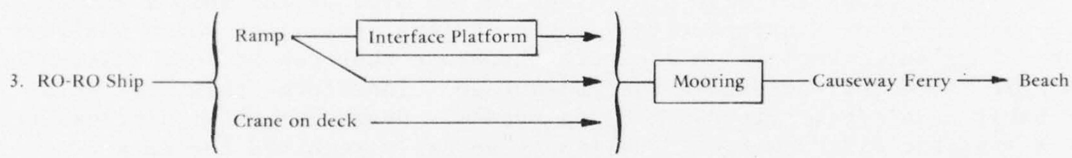
A third concept, intermediate in length, incorporates a breakwater and a single-point-mooring buoy for the ship into one structure. Since the force of the current on the ship's hull may be the dominant force in determining the ship's heading (see Appendix B), the area sheltered by the breakwater may vary as the current varies and the length of the wave barrier may be insufficient. Modularization of such a buoy-breakwater structure for transport by ship would be important in a COTS application.



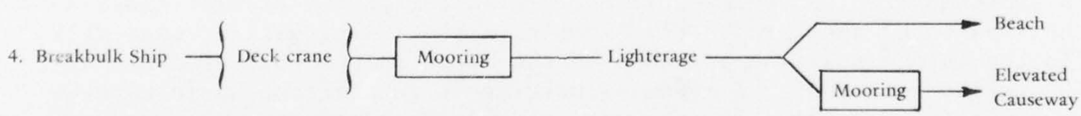
(a) Containership



(b) Bargeship



(c) RO-RO Ship



(d) Breakbulk Ship

LEGEND

BMA = Barge Marshalling Area

TCDF = Temporary Container Discharge Facility

= Moored platform or lighter

Figure 1. Cargo flow paths.

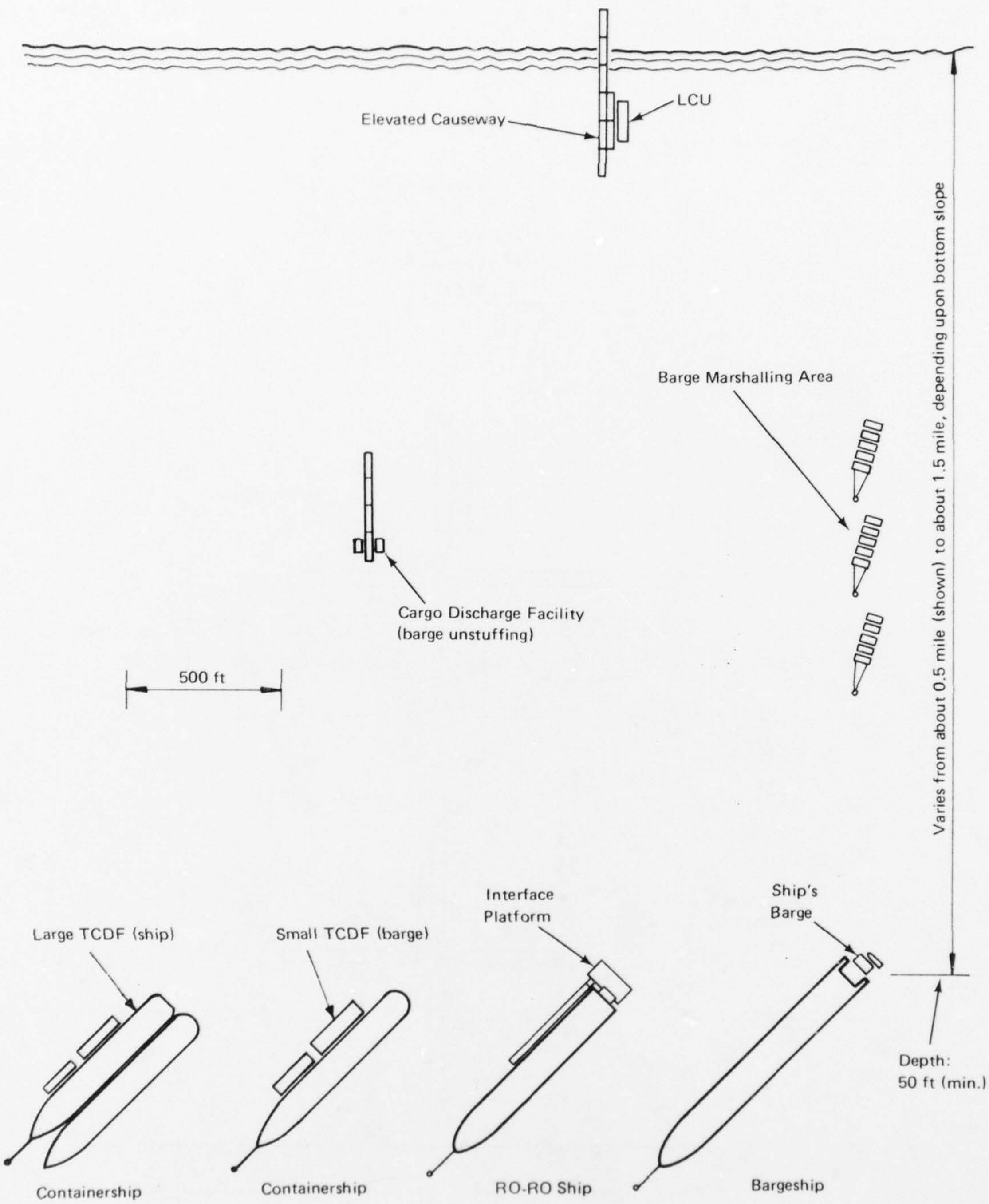


Figure 2. Schematic of facilities for cargo movement.

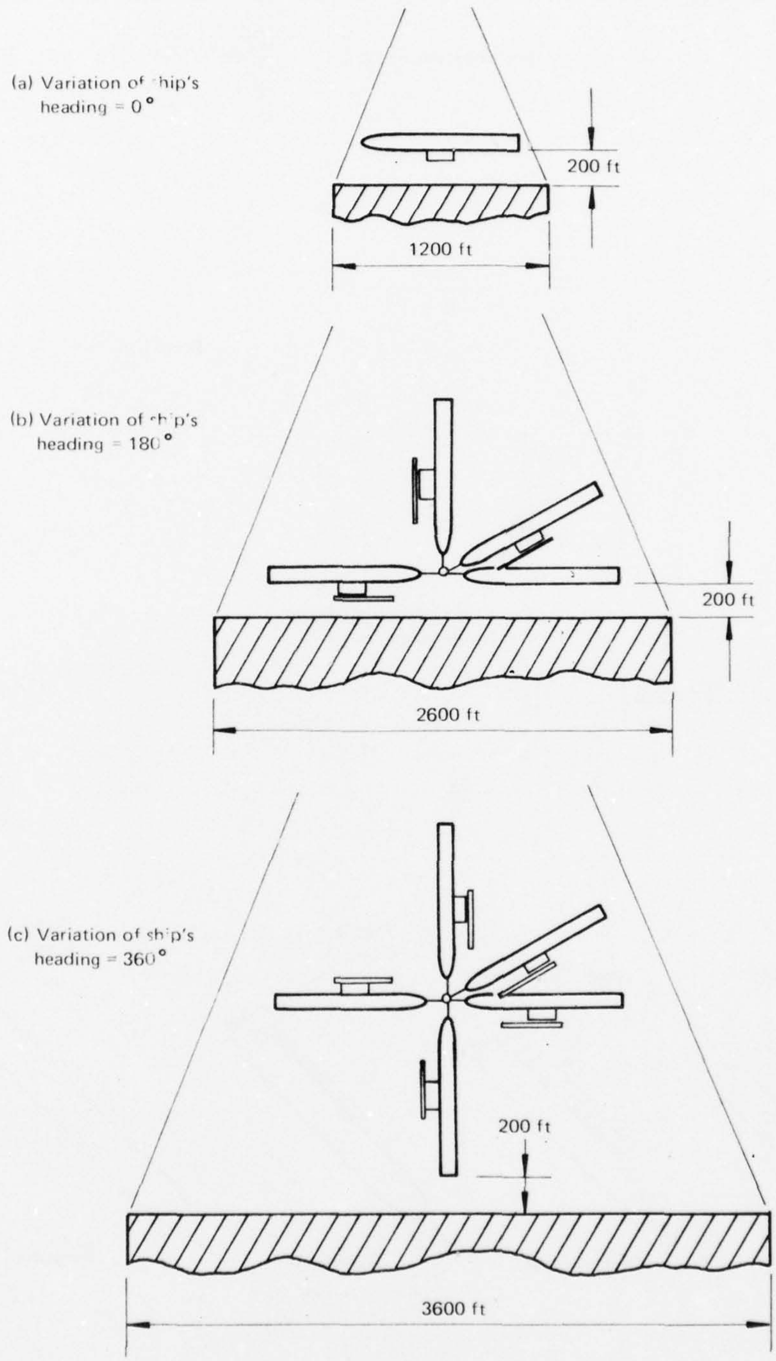


Figure 3. Hypothetical mooring situations, illustrating variation of required length of fixed breakwater with freedom of vessel to swing.

Barge Unstuffing at a Cargo Discharge Facility. When LASH barge cargo is transferred to lighters by a crane on a floating platform (a causeway string has been used in field tests) wave protection is particularly needed. A small crane platform responds to quite short waves, and removal of the hatch and the cargo is affected by motion of the platform. Suppression of even short-period waves would increase operational time. Unlike the barge TCDF at the containership complex, this crane platform is never in the shelter of a large ship. A breakwater of minimum length can be used if the platform is stationary, that is, not swing-moored; the required effective length would be about 500 feet.

Discharge of Cargo at the Elevated Causeway. Containers and breakbulk cargo carried by LCU's and other lighters would be unloaded by a crane located on the elevated causeway (Ref. 18). The smallest lighters are responsive to wave periods as small as 2 or 3 seconds. Circumstances for locating a breakwater at the elevated causeway are similar to those for the cargo discharge facility in that both structures are fixed in location; therefore, a fixed-location breakwater is feasible. A breakwater close to the causeway, however, would interfere with the maneuvering of lighters. A stand-off distance of at least 280 to 300 feet* would be required, necessitating an effective length of breakwater of about 600 feet, as shown in Figure 4.

Barge Marshalling. Temporary storage of full and empty barges at moorings in a barge marshalling area is very likely required for efficient use of the bargeship and convenience in bringing barges into, and extracting them from, the cargo transfer system. Seaworthiness of some of the barges is a moot question. Adequate wave protection would safeguard moored barges against damage or loss and would permit safe and efficient maneuvering and mooring of barges in the presence of waves. The wave period for which significant effectiveness of the breakwater is mandatory has not been established; however, considering the size of the barges, some benefit seems likely if the breakwater is designed for the same wave period as the other breakwaters described (7 seconds). The length of the breakwater would depend upon the number of barges and the barge mooring arrangements. A preliminary estimate of length for 80 barges is 2,500 to 3,500 feet.

Breakwater Selection

It is well known that the effectiveness of a floating breakwater of a given size falls off rapidly as the wave period increases. Equivalently, increased size is required to maintain a given level of effectiveness (for example, 50% wave height reduction) for increased wave periods. Seemingly small increases of the design wave period may result in significant increases of shipping cube and weight. In choosing the size, the key question is whether or not the breakwater is large enough to be beneficial yet small enough to be ship-transportable and otherwise logistically acceptable.

*This figure presumes that a lighter approaches the causeway moving against the alongshore current. Use of the causeway ferry around the elevated causeway is probably precluded.

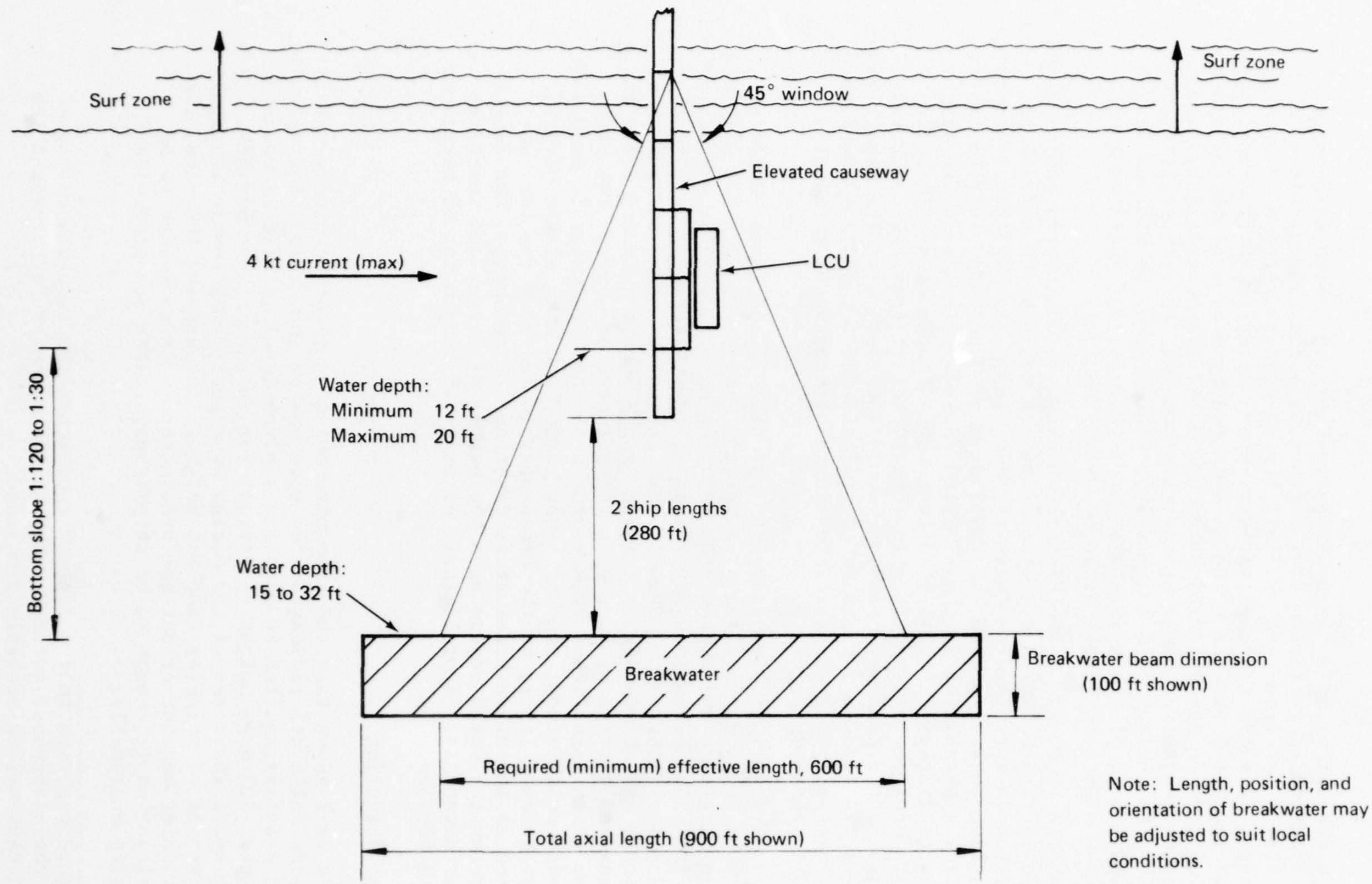


Figure 4. Breakwater for elevated causeway.

Evidently, a breakwater would be beneficial in several areas of COTS operations if it is effective for the wave periods to which the various small, moored platforms and lighters alone are most responsive - that is, periods from 2 to 7 seconds. Thus, the performance goal for a breakwater for sheltering these elements of the COTS should be some specified degree of wave height reduction when the dominant wave period is about 7 seconds. A specification of 50% reduction of the significant wave height is convenient for reference and seems adequate for the following reason: in a fully developed sea where the most energetic wave components have a period of 7 seconds, the significant wave height is 6.4 feet (Pierson-Moskowitz spectrum); in the lee of the breakwater the significant wave height would be 3.2 feet, which is a reasonable goal for operating COTS at full capacity.

By definition adopted for this study, a "7-second breakwater" is one that reduces by 50% the significant wave height in a storm-sea represented by the Pierson-Moskowitz spectrum with a 7-second peak period. As noted in discussions of particular breakwaters which follow, 7-second breakwaters tend to produce reductions of more than 50% if the dominant wave period is less than 7 seconds or if the wave spectrum is broader than the Pierson-Moskowitz spectrum. The total amount of time in a year (or season) during which operations would be upgraded by a 7-second breakwater would be the aggregate of times during which the height of the incident waves is greater than that which is critical for operations, but not clearly excessive, while simultaneously the dominant wave period is about 8 seconds or less. Whether or not a breakwater is actually beneficial obviously depends upon the wave climate.

THE TETHERED FLOAT BREAKWATER

Description

The tethered float breakwater is an array of floats individually tethered to and held submerged (or nearly submerged) by underwater ballast units. The ballast units are blocks, beams, frames, or raftlike structures that serve also to maintain the horizontal spacing of the floats at about two diameters, center-to-center.

In the floating version (see Figure 5), the ballast units are joined together into a larger unit, suspended above the bottom, and held in position by mooring lines and anchors. The moorings let the floats remain at the surface during tidal or other fluctuations of the mean surface elevation. The reserve buoyancy keeping the system afloat may be distributed uniformly among all the floats by maintaining a uniform length of the tethers, or it may be concentrated in a selected fraction of the floats by providing those floats with longer tethers than the rest, as in Figure 6.

In the bottom-resting version, excess ballasting mass insures that the ballast remains on the bottom. At low tide, the floats are held nearly submerged; at high tide, the floats are totally submerged.

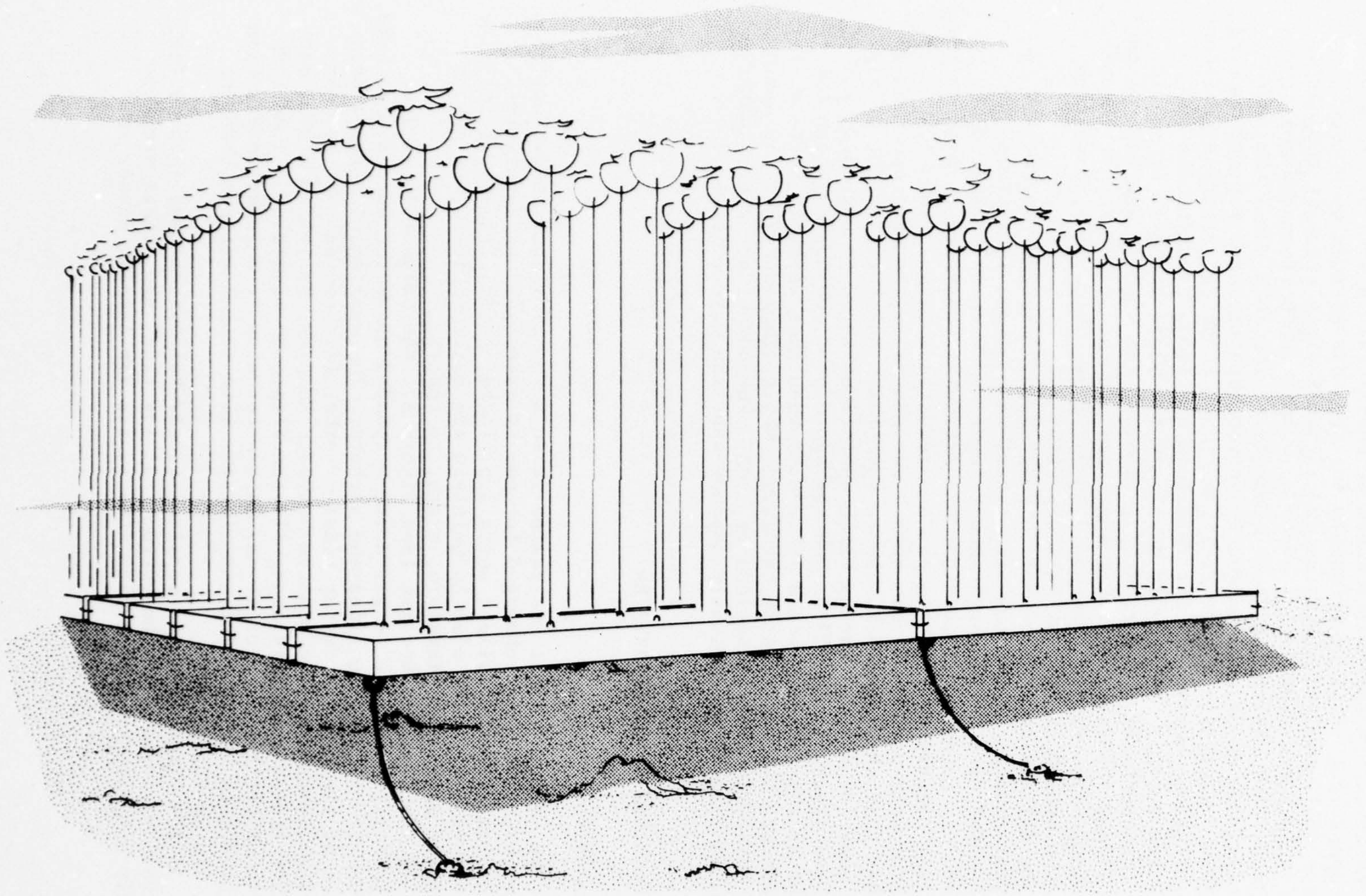


Figure 5. Tethered float breakwater, floating version.

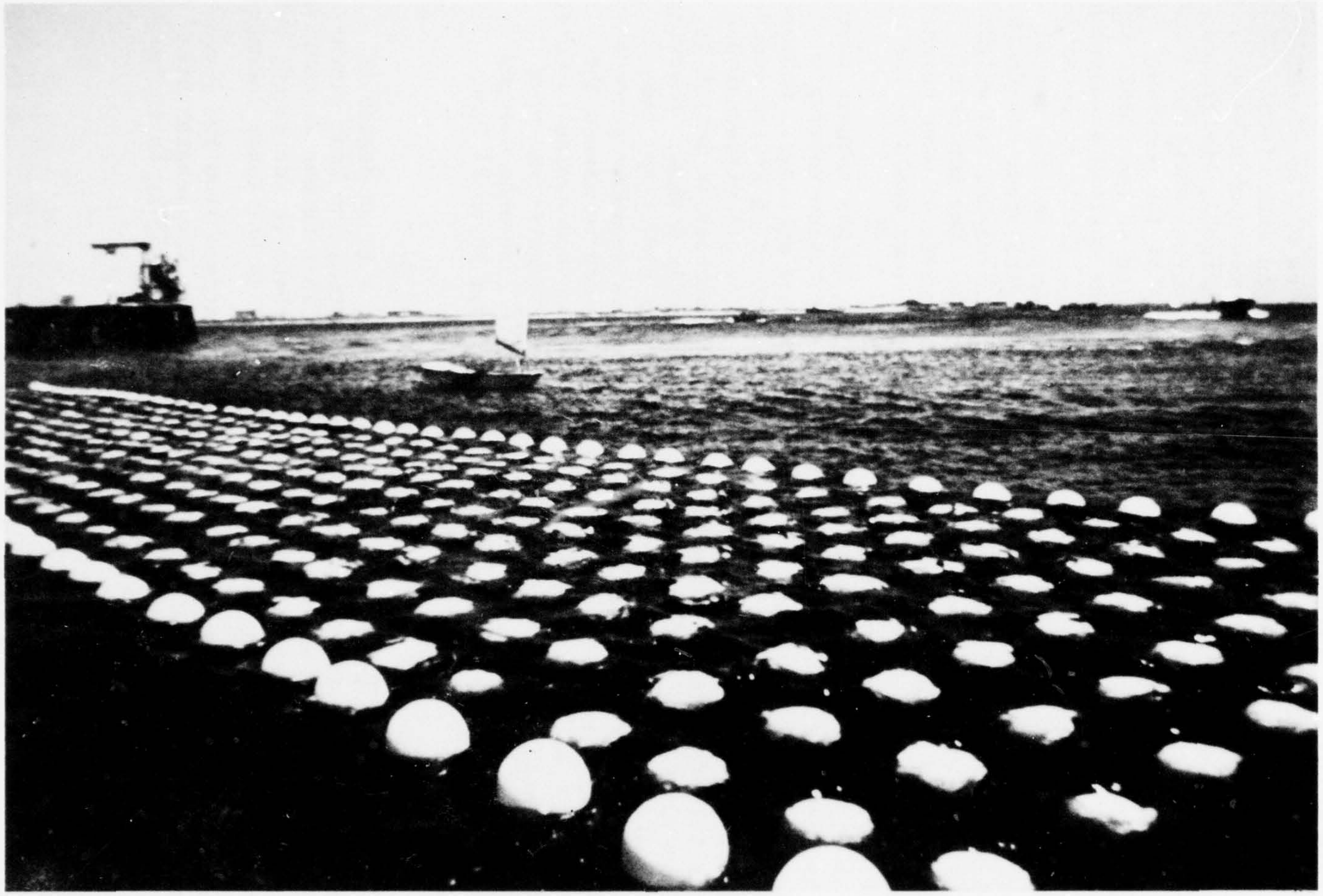


Figure 6. Floating tethered float breakwater with 12-inch spherical floats, designed for 2- to 3-second waves.

Performance Characteristics

The number of rows of floats required for a given degree of reduction in wave height is a fairly strong function of the size of the floats.* With the size of the floats fixed at some reasonable value (characteristic dimension of the order of the wave height), the system is most efficient (the fewest number of rows is required) when the length of the tethers is equal to a certain fraction of the dominant wavelength** and when the shape, density, and position of the floats are also optimized. For deep-water floating systems, the optimum arrangement evidently consists of spherical floats which weigh as little as possible, are positioned with tops submerged one-fourth diameter, and are spaced horizontally two diameters, and of tethers with lengths about one-tenth of the dominant wavelength (Ref. 6). Once the type, volume, and weight of the floats and the length of the tethers are fixed, the number of rows of floats may be varied to obtain different degrees of wave height reduction. A practical increment for the number of rows would be the sea-to-shore dimension of the ballast module.

Conceivably, it would be practical on occasion to use tethers that are somewhat longer than optimum in order to have a bottom-resting system instead of a floating system, thus eliminating moorings. Conversion of any existing floating system into a bottom-resting system would require additional ballasting mass. The reduction of effectiveness due to too-long tethers is small if the proportional increase in length is small, as the data presented in Figure C-3 in Appendix C show. However, with the floats fixed at about the low-tide surface elevation, some effectiveness during high tide is lost due to excessive submergence of the floats. Data with the generality and scope needed to assess the tide effect have not been reported. In one instance concerning 13-cu-ft tire-casing floats, the predicted reduction of the significant wave height for a wave spectrum with the peak period at 7 seconds changed from 80% to 56% when the depth of water changed from 18 to 24 feet (Ref. 19).

---

*Size selection tends to involve trade-offs. For a given degree of wave attenuation and for optimum deep-water systems, the beam dimension of the breakwater and the total number of float-tether assemblies in the breakwater decrease as the size of the floats is increased, but total volume of floats, handling difficulty, and tether loads increase.

**The length of the tethers is taken to be the distance from the lower termination to the center of the float. "Dominant wavelength" here equals $gT_p^2/2\pi$, where T_p is the wave period corresponding to the peak of the wave spectrum.

In shallow water, where use of a bottom-resting system with tethers shorter than the deep-water optimum may be forced by circumstances, the reduction of performance associated with the mismatch of the natural frequency and the wave frequency comes on rather abruptly (see Figure C-3); but apparently, performance may be fully or partly restored by use of cylindrical floats, increased density of the floats, and closer spacing of the floats in the direction normal to the direction of wave propagation. Thus, optimization requires consideration of additional variables. Performance sensitivity to changes in these variables is not yet known, but it appears to be an important planning consideration. For example, knowing in advance the effect of changing the length of the tethers by 10 feet in order to move the breakwater into 25 feet of water from 35 feet, or vice versa, would be important.

Depth Limits for Floating Systems

Estimates for the minimum allowable depth of water for a floating system, to prevent contact between the ballast and the seafloor, are given in Table 2 and are based on the following conditions and assumptions (geometric quantities are defined in Figure 7):

1. The system is optimum: the floats are spherical; the centers of the floats are submerged three-fourths diameter ($z = 0.75D$); the float density is minimal; and the length of the tethers is optimum ($\ell = gT_p^2/20\pi$).

2. The floats are 5 feet in diameter.

3. Wave conditions are represented by the Pierson-Moskowitz spectrum for fully aroused wind-generated seas.

4. The vertical dimension of the ballast is the float diameter ($h = D$).

5. The minimum clearance beneath the ballast is one-half the expected maximum wave height, taken arbitrarily to be twice the significant wave height for a Pierson-Moskowitz spectrum with a peak period 25% greater than the peak period used for design (see the second column of Table 2). Thus, minimum C (feet) = $0.21\ T_p^2$.

Table 2 indicates appropriate depths of water for various design wave periods, but these should be used only as a general guide. In practice, the minimum depth should be determined on the basis of local wave conditions and particular performance requirements. Thus, if the highest waves are not expected to be as high as the values used to construct Table 2 (height in feet = $0.42\ T_p^2$), the clearance beneath the

ballast could be reduced. If maintaining performance, particularly for wave periods greater than the design period, is not important, the tether length could be reduced.*

Table 2. Guide For Minimum Water Depth For Floating Tethered Float Breakwater With 5-Foot Spherical Floats

Sea State	Dominant Wave Period, T_p (sec)	Optimum Tether Length (ft)	Minimum Water Depth (ft)
2-1/2	4	8	20
3	5	13	27
3-1/2	6	18	35
4	7	25	44
5	8	33	55
5	9	41	67
6	10	51	81
6	11	62	96
6	12	74	113

*The effect of shortening the tethers is shown by the example of the following table, derived from Appendix C.

Dominant Wave Period, T_P (sec)	Reduction of Significant Wave Height (%)	
	25-ft Tether	17-ft Tether
7	50	44
8	34	22

The 33% reduction of tether length affects performance for a spectrum with an 8-second peak period more than for the design spectrum of 7 seconds. It is emphasized that these values apply to 5-foot spherical floats of low density, with centers submerged 3.75 feet, and to Pierson-Moskowitz wave spectra.

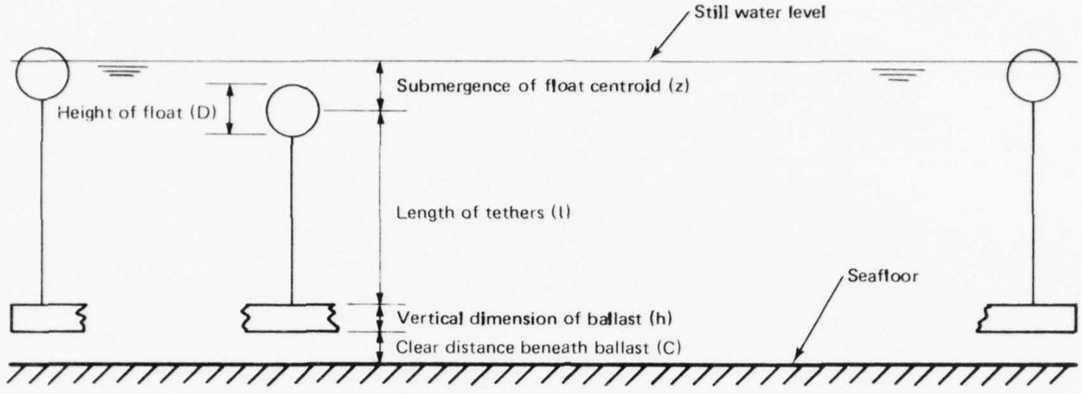


Figure 7. Tethered float breakwater: definition sketch of geometric quantities.

Performance Summary

Figure 8 summarizes the performance of optimum floating systems in fully developed, local-wind-generated seas, as represented by the Pierson-Moskowitz spectrum.* Figure 8, derived from Figure C-1, shows the optimum tether length and the number of rows required to reduce wave heights to levels associated with sea state 3. For example, for a spectrum peaked at 7 seconds (significant wave height 6.4 feet), the optimum tether length is 25 feet; and the significant wave height is reduced to 5 feet if the breakwater has 17 rows, to 4 feet if it has 26 rows, or to 3 feet if it has 42 rows. A 7-second breakwater has 38 rows, by interpolation in Figure 8 or by Figure C-1. The performance of a 38-row breakwater for other wave spectra is summarized in Table 3.

Figure 8 and Table 3 pertain to 5-ft diameter spheres each of which weighs less than 400 pounds (relative density less than 10%). A commercial product could be available if the demand were sufficient. As noted previously, a low-density sphere is optimum for a floating (deep-water) system. Figure 8 and Table 3 also pertain to an approximate tether length of 30 feet ± 20%. According to Figure C-3, variation within this range has little effect on performance for spectral peak periods between 6 and 9 seconds. However, as the tether length is varied farther from this range, additional rows of floats would be required to maintain 7-second breakwater capability.

*Performance is more fully described in Appendix C.

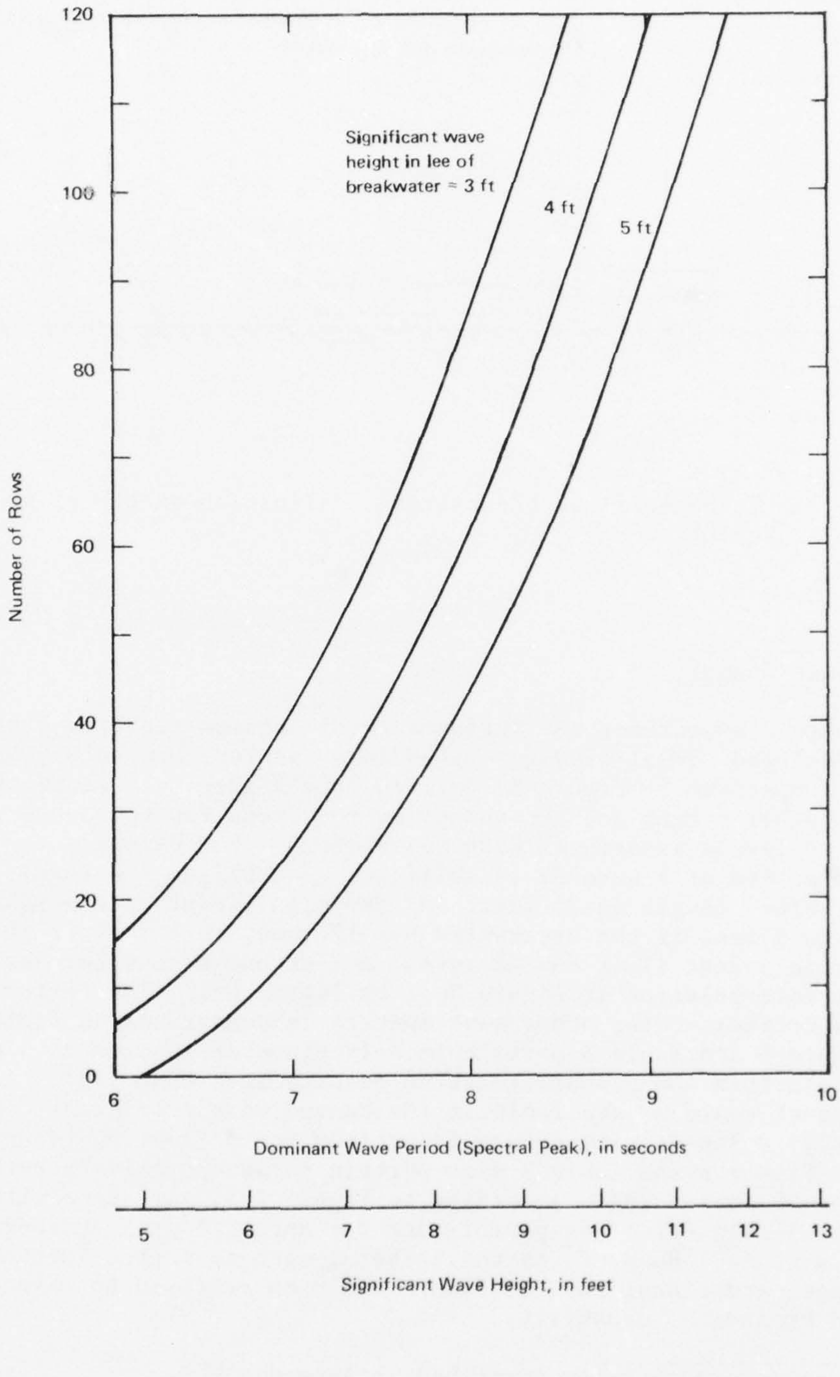


Figure 8. Number of rows of 5-foot spherical floats required to reduce wave heights (Pierson-Moskowitz spectrum) to sea state 3 levels.

Table 3. Floating Tethered Float Breakwater: Performance Summary For 38 Rows of 5-Foot, Spherical, Low-Density Floats

Peak Period of the Incident Wave Spectrum (sec)	Pierson-Moskowitz Spectrum			Modified Spectrum[a]	
	Significant Wave Height (ft)	Sea State	Reduction of Significant Wave Height (%)	Significant Wave Height (ft)	Reduction of Significant Wave Height (%)
4	2.1	2-1/2	>90	0.9	88
5	3.3	3	86	1.4	83
6	4.7	3-1/2	69	2.0	79
7	6.4	4	50	2.7	73
8	8.4	5	34	3.5	66
9	10.6	5	22	4.4	57
10	13.1	6	11	5.5	no datum

[a]See Appendix D.

According to Table 2, the minimum allowable depth of water corresponding to the optimum tether length of 25 feet is 44 feet, the clearance beneath the ballast being 10 feet. Circumstances could permit some reduction of this depth.

Description of Three Specific Designs

A breakwater's mass, shipping cube, cost, and other important properties that determine the total logistic burden depend upon several physical properties, the most important of which are (1) volume and density of the floats and (2) materials and configuration of the ballast system.

Three designs with significant differences in float and ballast properties have been initiated and carried to varying degrees of completion. Two are floating systems; the third is a bottom-resting system. These designs are described, and an attempt is made to evaluate certain

aspects of logistic significance – transportation, installation, and cost. For the bottom-resting system the evaluation is incomplete. Logistical properties such as cost and shipping cube per increment of axial length, which are functions of the beam dimension of the breakwater, are omitted since performance data covering the expected ranges of depth, submergence, and float properties are a necessary input.

Design T1 (Floating): 5-Foot Spheres, Concrete Barge-Type Ballast.

1. Background. A conceptual-design study was undertaken at the Civil Engineering Laboratory (CEL) in 1975 to develop a ship-transportable ballast module (Ref. 20). Figures 9 through 13 depict one of several similar concepts developed for 5-foot spherical floats. The ballast structure is of reinforced concrete. The type of construction illustrated in Figure 9 is similar to one developed for a concrete landing craft during World War II. A full-scale, concrete LCT (length, 112 feet; beam, 32 feet; weight, 224 tons) was tested for 1-1/2 months. The ship was driven at full speed onto hard and soft beaches under simulated wartime conditions and found at the end of the tests to be unscathed (Ref. 21). The structural integrity of landing craft may not be required for the breakwater ballast. Several variations of the concept involving simpler, faster construction were subsequently developed.

2. Design Features. Each module carries a 4x7 array of floats (see Figure 10). Both columns and rows of floats are spaced at 10 feet. Five rows of modules contain 35 rows of floats, which is almost the number required for a 7-second breakwater. Sets of 15 modules, lashed together, form a moored element. Alternate moored elements are displaced seaward, as shown in Figure 11. This staggered or checkerboard layout was developed to facilitate mooring. A checkerboard array made up of nine moored elements (see Figure 11) has an axial length of about 1,070 feet and an effective length (see Appendix E) of about 640 feet.

This concept's salient feature is that the module is a barge which can be towed short distances, carrying its complement of floats to the point where it is to be installed (see Figure 12), and which can also be transported over the ocean by various means. Upon delivery to the site, the floating modules can be immediately unloaded from the transport ship or barge and temporarily stored at moorings or on the seafloor without pre-empting the use of ships, barges, or dock space for storage. Another feature is a provision to refloat the module by introducing low-pressure air into the chambers in the trough-like structural members (see Figure 13). The prefabricated structural members may be transported over land. Other options are available for the flooring (e.g., mesh) and for flotation (e.g., bags). In short, the goals (system properties) – versatility with respect to the mode of transportation, and minimum installation and retrieval time – were approached through use of the largest size of preassembled units that do not make handling excessively difficult.

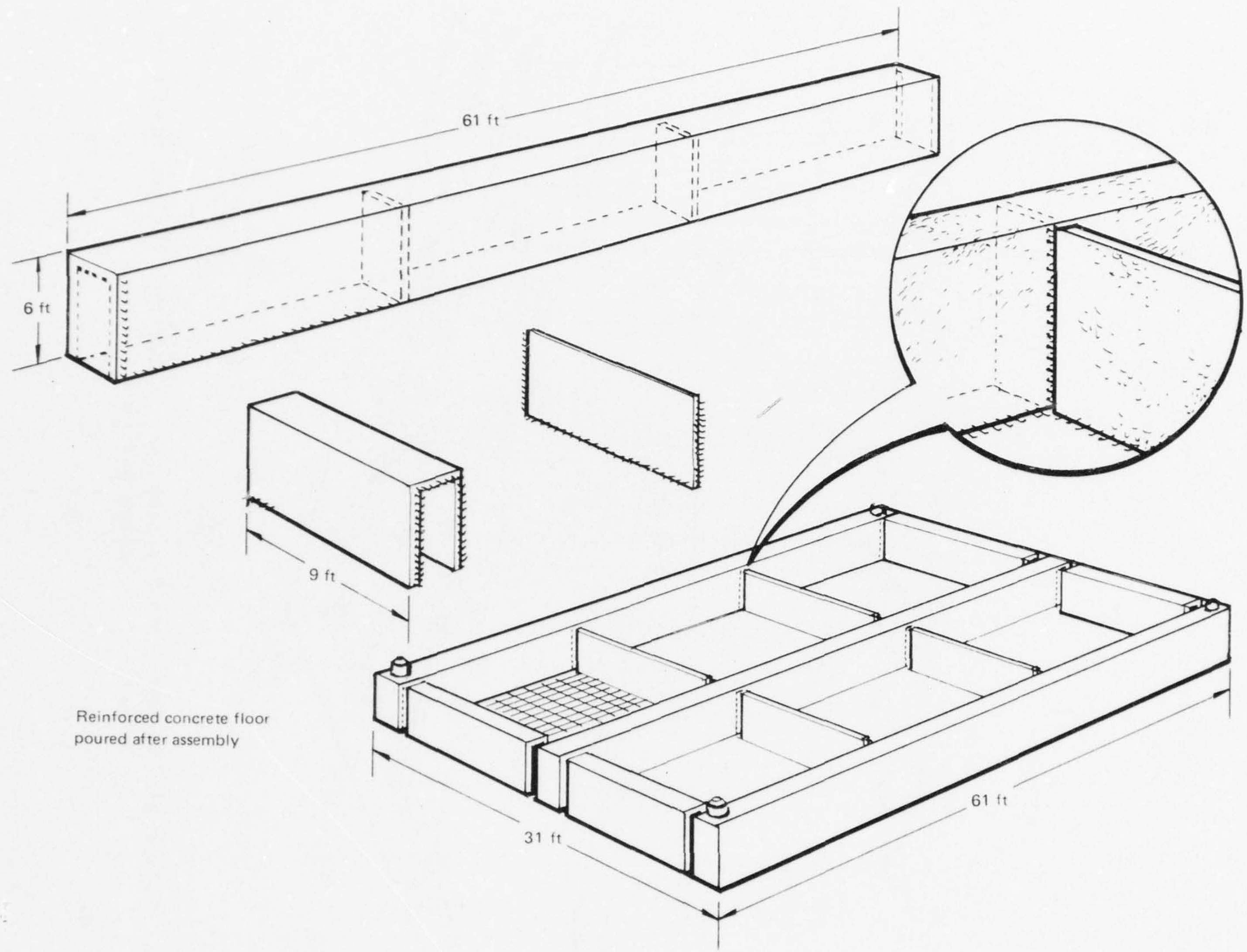


Figure 9. Tethered float breakwater: reinforced-concrete, barge-type ballast module.

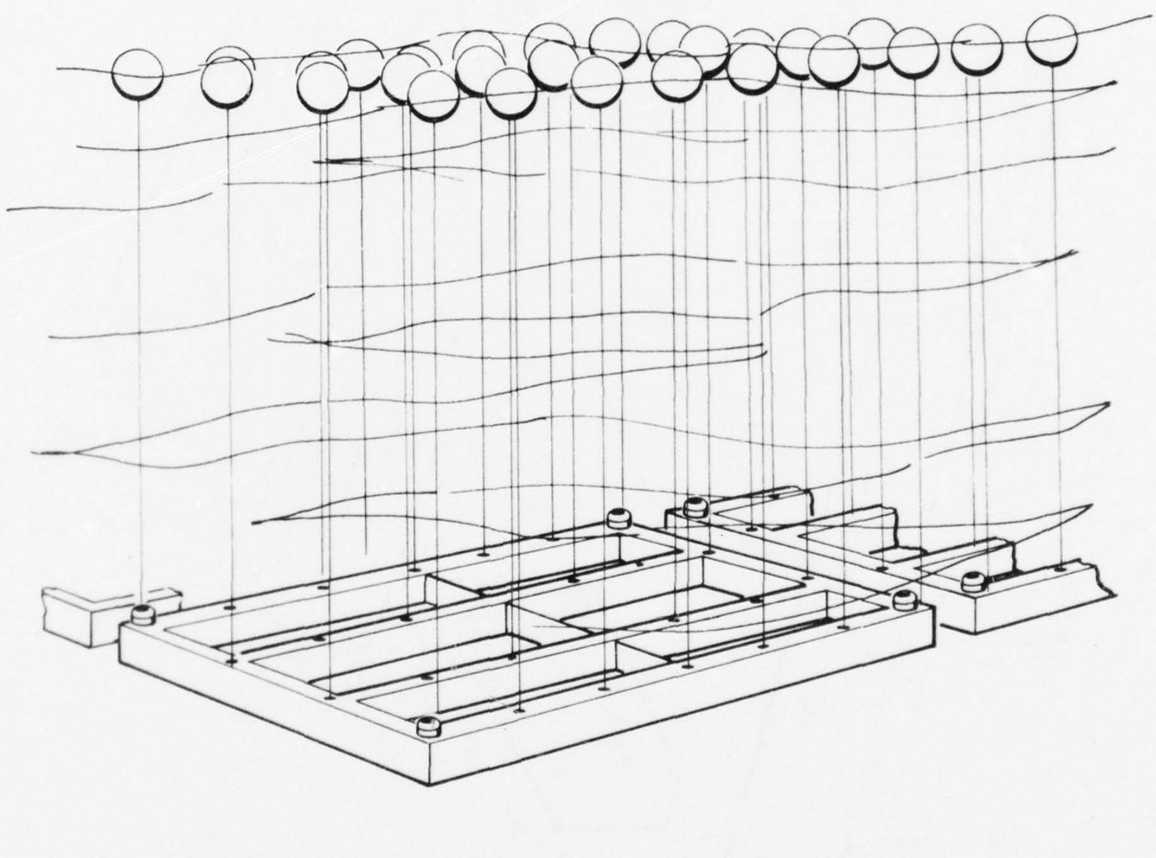


Figure 10. Tethered float breakwater: barge-type ballast module in submerged, operating position.

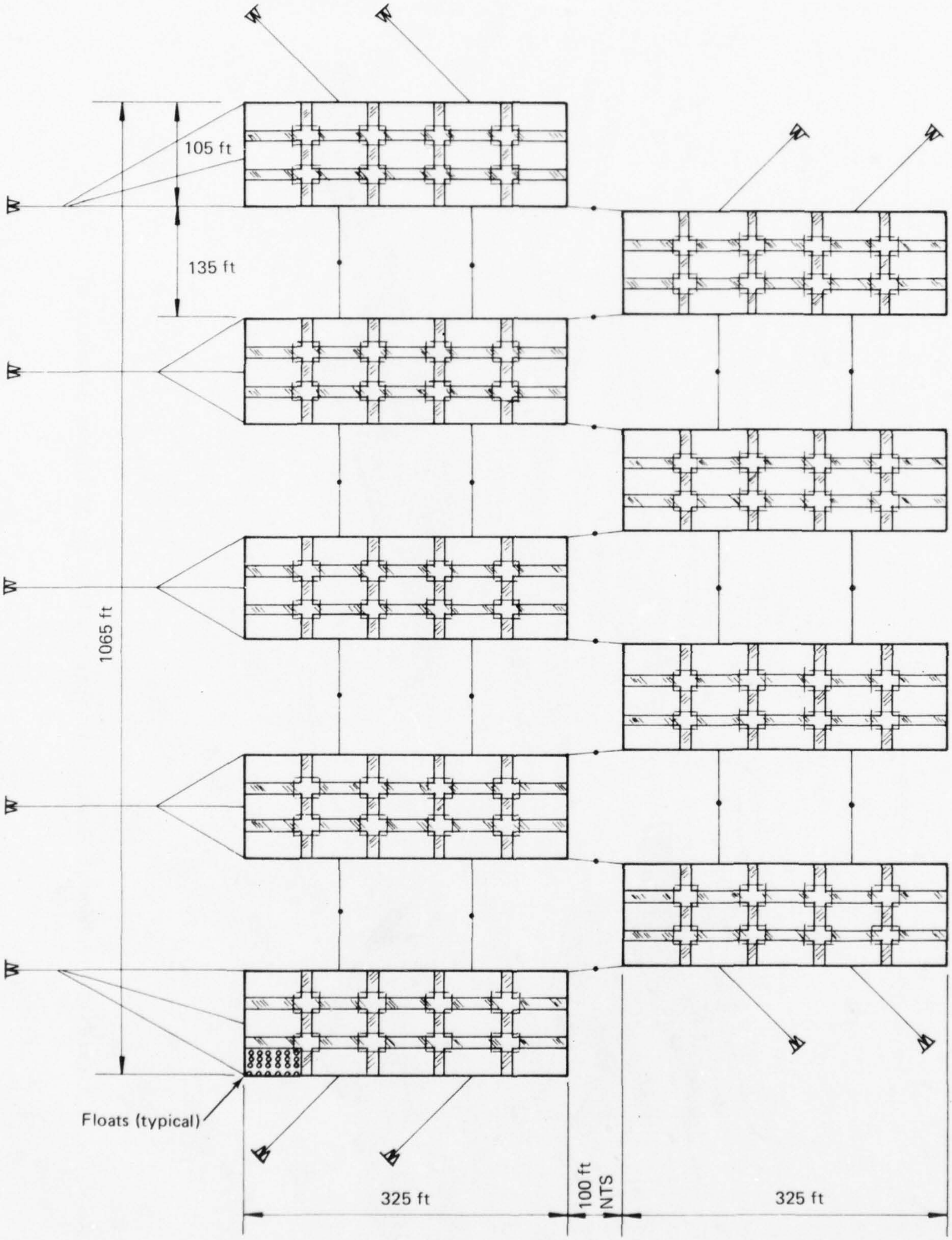


Figure 11. Tethered float breakwater: layout of barge-type, design T1 modules.

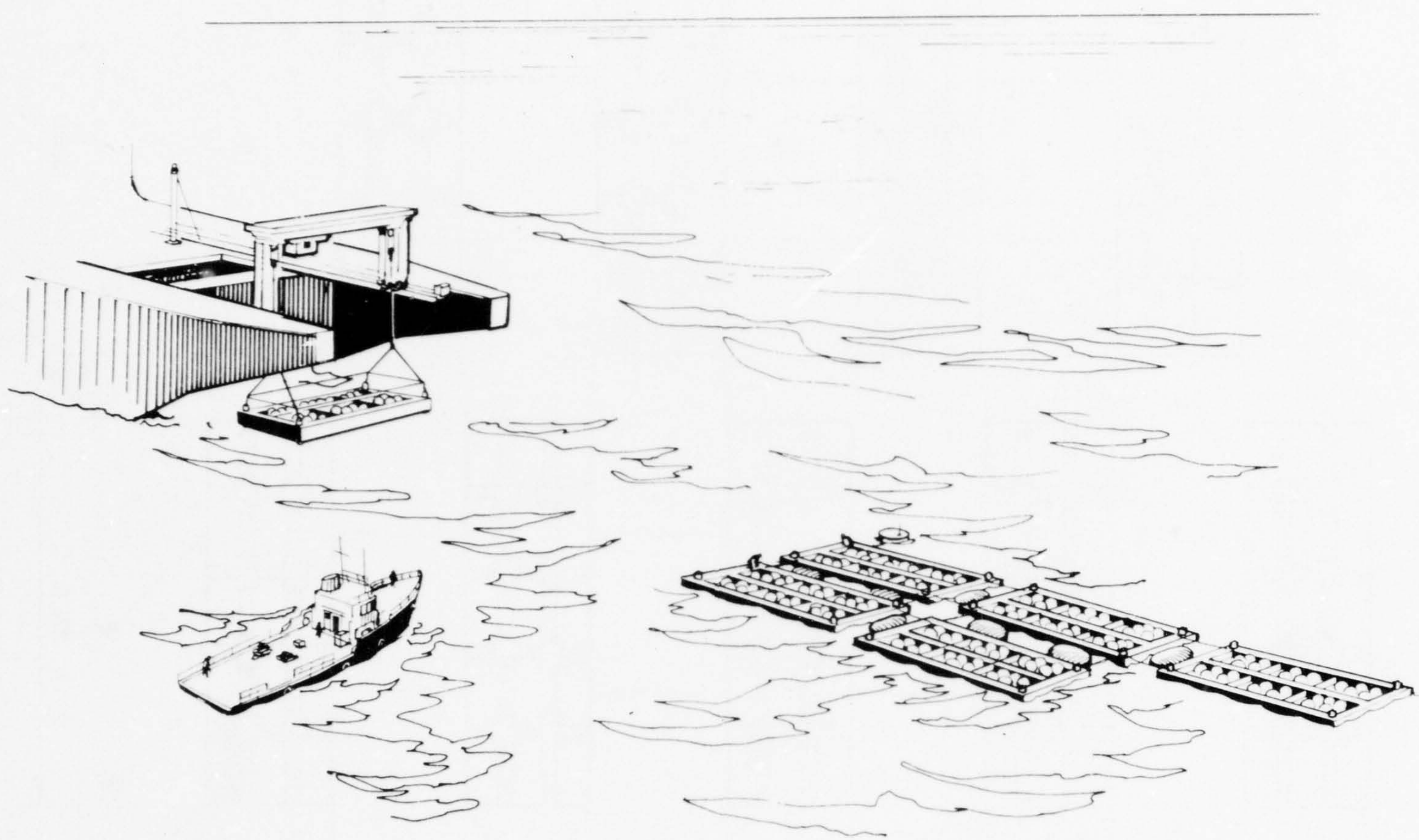


Figure 12. Tethered float breakwater: assembly of moored elements of design T1.

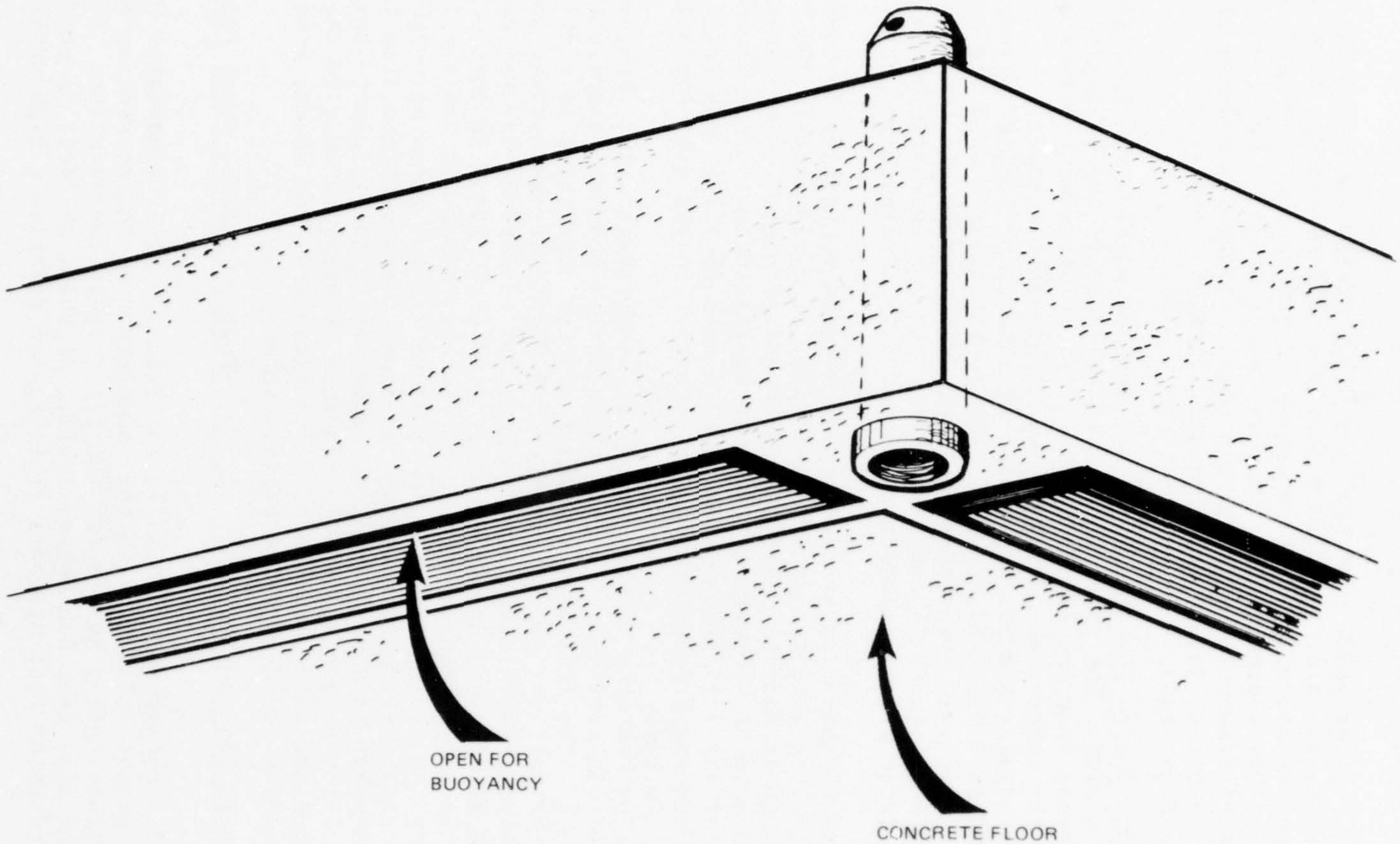


Figure 13. Tethered float breakwater: buoyancy compartments and lifting post for T1 module.

Design T2 (Floating): 5-Foot Spheres, Concrete Articulated-Frame Ballast.

1. Background. The Tethered Float Breakwater Ocean Experiment project office, in 1976, selected a flexible ballast concept from several design proposals solicited from industry. A contract was awarded to Global Marine Development, Inc., Newport Beach, Calif. The T2 design is an articulated framework of relatively small, triangular modules of reinforced concrete, joined together with flexible connectors at their apexes (see Figure 14).

2. Design Features. The modules are equilateral triangles, 20 feet on a side. The cross section of the legs of the triangles is about 12 inches wide and 19 inches deep. Float attachment points are located on the connectors and at the midpoints of the sides.

The triangular modules are assembled into an articulated frame normally 100 feet wide (Figure 14). The length depends upon the number of rows of floats. A breakwater is composed of several of these large assemblies (see Figures 15 and 16). The staggered or checkerboard layout for large moored elements was originally developed for this design.

The sea-to-shore length of a moored element containing 37 rows of floats would be 312 feet. If 100 feet wide, it would contain 346 floats and 81 triangular modules. Nineteen such moored elements in a staggered array would make up a breakwater with an overall beam (sea-to-shore dimension) of 724 feet and a total axial length of 1,900 feet (Figure 15). This is a 7-second breakwater with an effective length (see Appendix E) of about 1,500 feet.

The major features of the concept are its flexibility, obtained through numerous articulations, and the concrete modules' simplicity and low unit cost. The flexibility permits greater amplitudes in vertical motion of the ballast, eliminating concern about extreme dynamic loads in the tethers; however, this concern may not be serious for the wave periods and float sizes now being considered (Ref. 22). Another consequence of the flexible-ballast concept is that components are small (the heaviest are the 6-1/2-ton triangles and the 1/2-ton trimming weights), permitting relatively easy handling, overland transportation from the fabrication plant to a waterfront assembly site, and efficient stowage on a barge for overseas shipment. Buoyancy is provided only in the floats. Once assembled and placed in sufficiently deep water, a moored element would be towed with the ballast submerged.

Design T3 (Bottom-Resting): 2- by 4-Foot Cylinders, Steel Frame Ballast.

1. Background. In 1977, the Tethered Float Breakwater Ocean Experiment project office, with the concurrence of the sponsoring agencies, chose a bottom-resting system for the first ocean installation. The depth at the site near San Diego, Calif., is about 25 feet. A performance analysis indicated that cylindrical floats of relatively high density

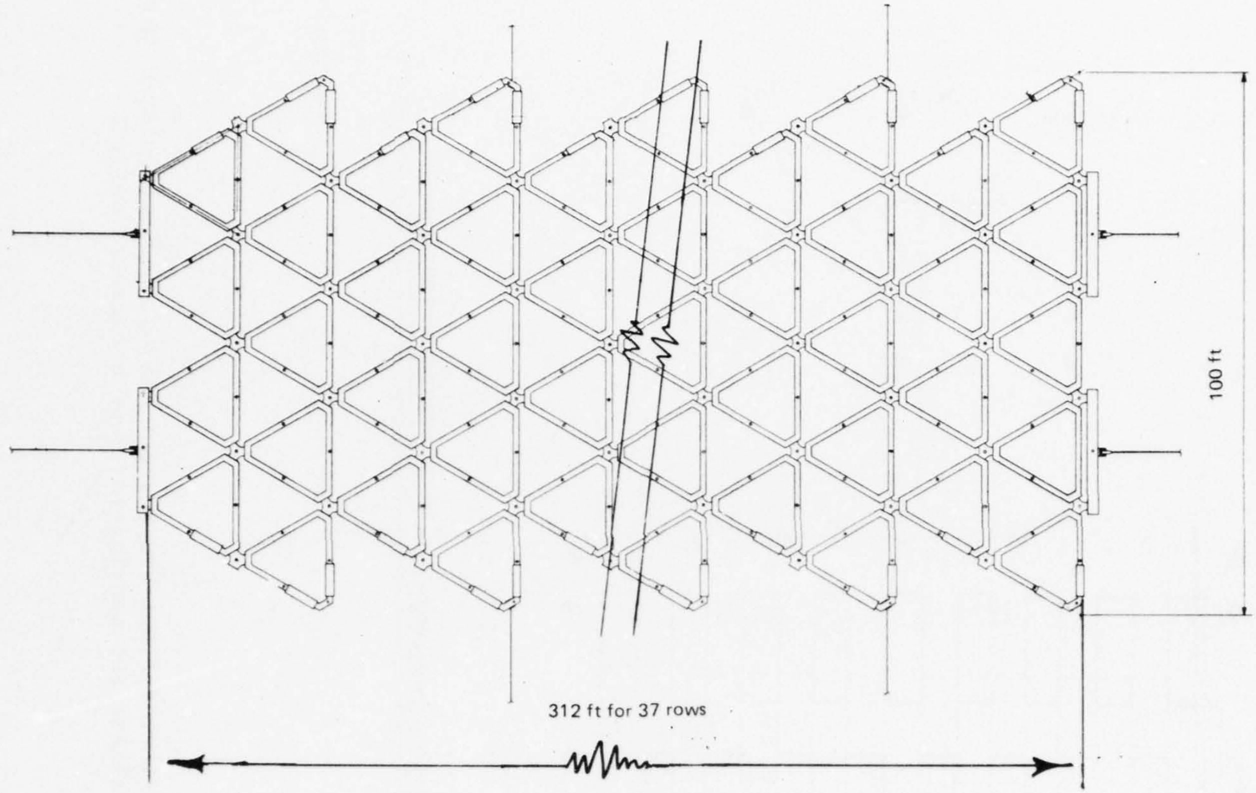


Figure 14. Tethered float breakwater: articulated-frame ballast.

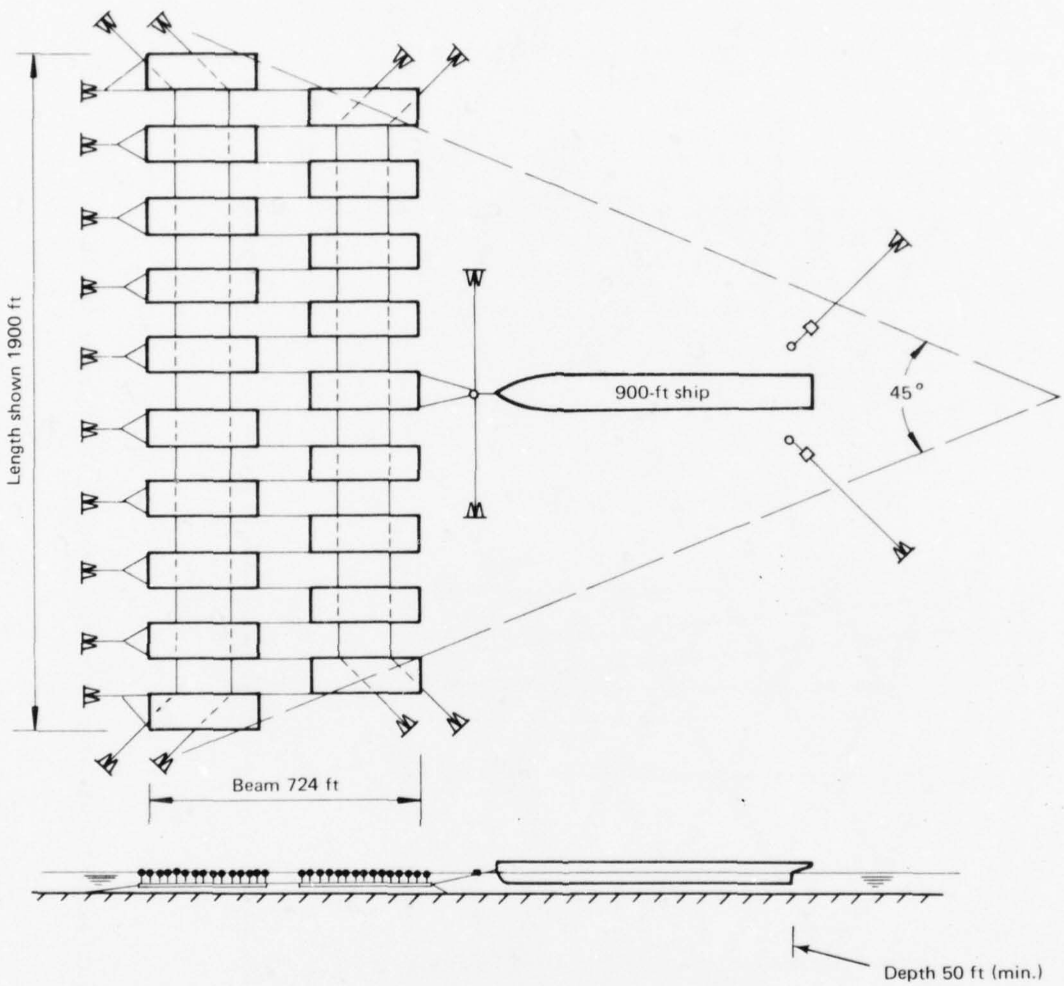


Figure 15. Tethered float breakwater: layout for articulated-frame ballast and mooring for weak alongshore current.

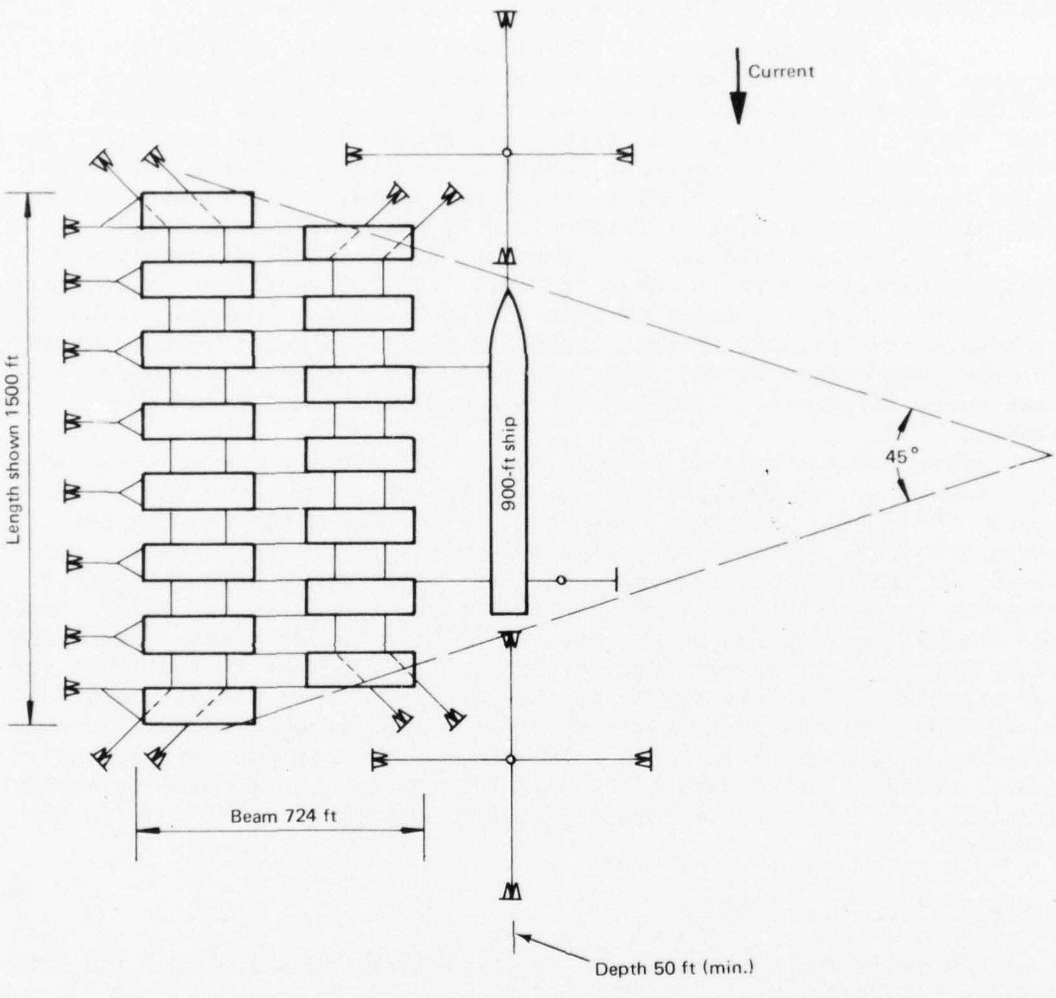


Figure 16. Tethered float breakwater: layout for articulated-frame ballast and mooring for strong alongshore current.

would be the most efficient. The Naval Ocean Systems Center (NOSC) developed a design for floats made from scrap automobile tire casings and a design for a ballast module compatible with the float properties. Installation of two modules took place in April 1978.

2. <u>Design Features</u>. The float is a stack of five or six tire casings. The interior of the stack is filled with polyurethane foam, and the top and bottom of this foam core are capped with concrete. A steel hook for connecting the tethers is embedded in the concrete. The float is essentially a cylinder, about 2 feet in diameter and 4 feet high; the weight of the float is about 475 pounds, which is 56% of its maximum displacement (the relative density of the float is 0.56).

The ballast module is a rectangular, welded steel framework made from scrap railroad rails, about 60 feet long, 30 feet wide, and 4 feet high (see Figure 17), weighing about 115,000 pounds. Mounted within the framework are four cylindrical tanks, 55 feet long and 3 feet in diameter. The plan dimensions of the frame were chosen to approximate those of a LASH barge (lighter). Attached to each module are 128 tire-casing floats.

Important features of the ballast design are the use of scrap metal for economy and of buoyancy tanks for retrieval. When the tanks are empty, the ballast module is suspended by the 128 floats. When the tanks are fully flooded, the ballast module rests on the bottom. The weight of the ballast is about twice that which would produce neutral buoyancy for the entire assembly. Thus, when the tanks are fully flooded, *the foundation reaction on one module is about 50,000 pounds*. With the tanks empty, a net upward force of about 50,000 pounds is available for raising the ballast off the seabed. A module of this design would be towed about with ballast submerged or else floated by means of add-on buoyancy. Upon being unloaded from the transport ship or barge, the module would be taken directly to the breakwater site or else to another area where it could be temporarily stored by ballasting it down to the seafloor.

<u>Logistic Aspects - Summary</u>

The following paragraphs on transportation, installation, and cost summarize portions of Appendix C.

<u>Transportation</u>. Overseas transport of the various breakwater modules would require ocean-going barges, certain ships with well decks, or bargeships (SEABEE or LASH). Since barge transportation is relatively slow and well-deck ships and SEABEEs are not likely to be available, the most likely carrier is a LASH. Table 4 shows the number of breakwater modules and the corresponding number of lineal feet of a 7-second breakwater that could be carried on one LASH. LASH bargeships cannot carry design T2 modules pre-assembled into moored elements; pre-assembly would be accomplished in the general area of the breakwater site.

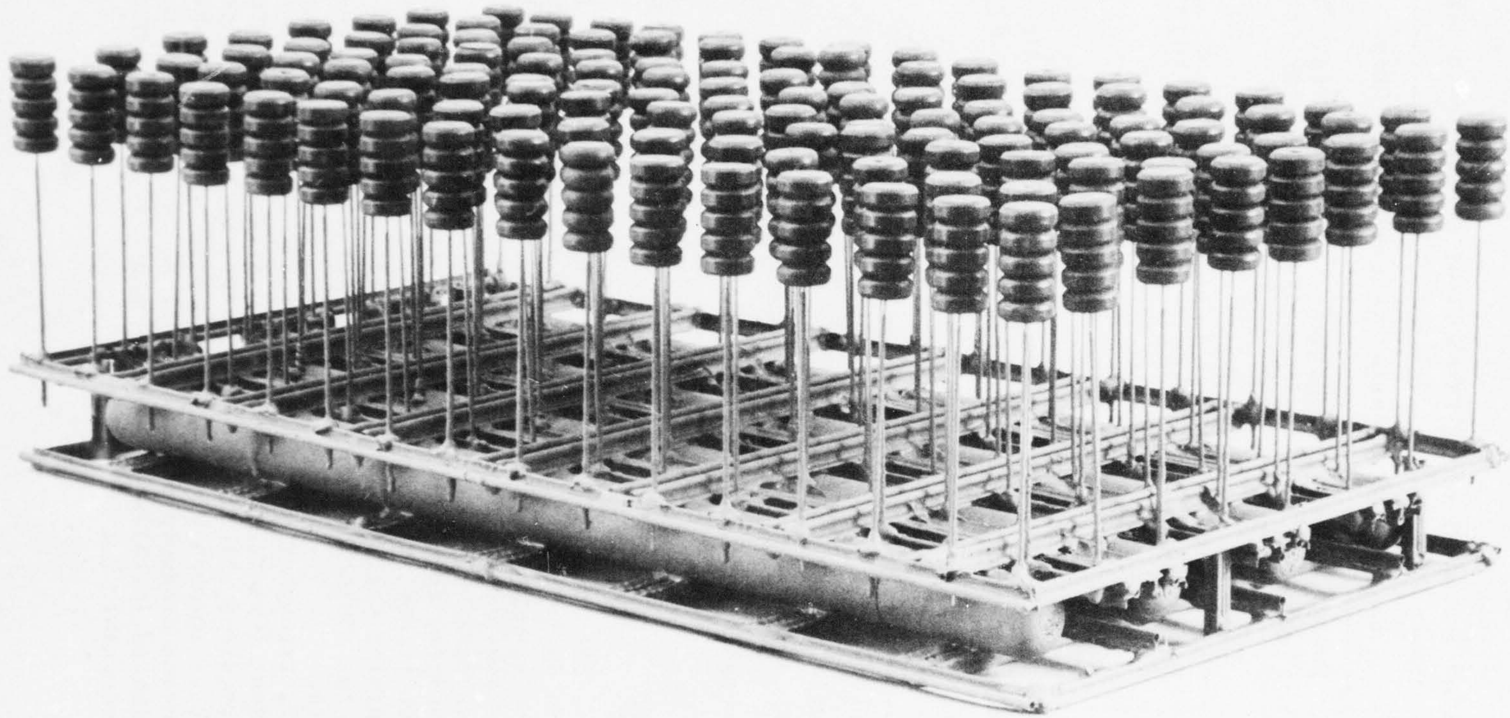


Figure 17. Shallow-water bottom-resting tethered float breakwater model (photograph courtesy of the University of California, San Diego, Scripps Institution of Oceanography).

Table 4. LASH Transport of Tethered Float Breakwater Modules

Breakwater Design	Quantity of Material Carried On One Ship[a]		
	Number of Modules	Number of Moored Elements	Axial Length of Breakwater (ft)
T1	154-242[b]	c	1,200-1,900
T2[d]	648-1,215	8-15	800-1,500
T2[e]	0	0	0
T3	f	c	f

[a] Range of values corresponds to the range of capacities of LASH ships.

[b] 56 to 64 modules on hatch covers plus 98 to 178 modules below deck in the spaces normally occupied by the ship's lighters.

[c] Not applicable.

[d] Modules not assembled into moored elements.

[e] Modules assembled into 100 by 312-foot moored elements.

[f] No data.

Installation. For design T1, a procedure for installation, in general outline, is as follows: (1) preset forward (seaward) anchors and forward upcurrent anchors (Figure 11), (2) tow offloaded modules successively to assembly point and assemble modules into a moored element (Figure 12), (3) successively attach moored elements to moorings, (4) sink ballast modules, and (5) adjust moorings. The estimated installation rate is roughly 200 ft/day, based on 12-hour days. Three vessels would be required: a warping tug; an ARS, ATF, or ATS; and a 3,000- to 5,000-hp tug. The warping tug would introduce the only drain on amphibious construction assets.

For design T2, transport on a LASH requires that modules be assembled into a moored element (Figure 14) in a forward area. A quiet-water assembly site is required which accommodates 100- by 312-foot moored elements and which is located within towing distance of the breakwater site. If simultaneous assembly of two or more moored elements is not feasible, the estimated installation rate is about 100 ft/wk, which appears to be unacceptable for COTS.

For design T3 (see Figure C-5), one possible installation procedure consists of offloading each module by use of the ship's gantry crane, attaching an auxiliary flotation system to the ballast module before the crane releases the load, moving the module to the breakwater site, positioning the module, sinking the module, and retrieving the auxiliary flotation. Five boats would be required - two LCM-8's and three 35-foot workboats.

Cost. Estimates of the fabrication cost of the breakwater are $5,300 per front foot for design T1 and $5,100 per front foot for design T2. No estimate is made for design T3 because the performance data on which cost per front foot is based are as yet unreported.

THE SLOPING FLOAT BREAKWATER

Description

The sloping float breakwater is a row of flat hollow panels or slabs which, when at rest, lie in an inclined plane with the lower ends of the panels ballasted and resting on the seafloor and the upper buoyant ends protruding above the water surface (see Figure 18). The upper end of a panel is the seaward end.

Various panel constructions are possible. An existing design may be adapted, such as a large, single float like an Ammi pontoon, or an assembly of small pontoons like a Navy Lightered (NL) pontoon barge; or a special design could be developed (e.g., a thin "tank" of concrete).

When unballasted, the module floats at the surface. For installation, one end is flooded until it rests on the bottom and the upper end settles to the elevation which produces the desired freeboard. Conventional moorings are attached near the upper ends of the modules. Alternatives to flooding are special ballast masses or special flotation units for sinking or floating, respectively.

In the original concept, the barrier extends all the way to the seafloor. In an alternative untested version, legs added to the float create a gap between the lower edge of the barrier and the seafloor. The gap may be required to reduce scour, and the addition of legs is desirable to increase the range of depths in which a panel of a given size can be used. The addition of legs could increase the usable depth range by about 50%. If the legs are retractable, the increase in depth range can be obtained with negligible increase in shipping cube.

Performance Characteristics

Wave attenuation by a sloping float breakwater appears to depend primarily upon reflection of wave energy. In the original concept, the incoming waves encounter a barrier which occupies the entire water column. Waves in the lee exist largely because of motion of the structure; this is resisted by inertia and gravity. The sloping float is effective over a relatively broad range of wave periods because it intercepts all

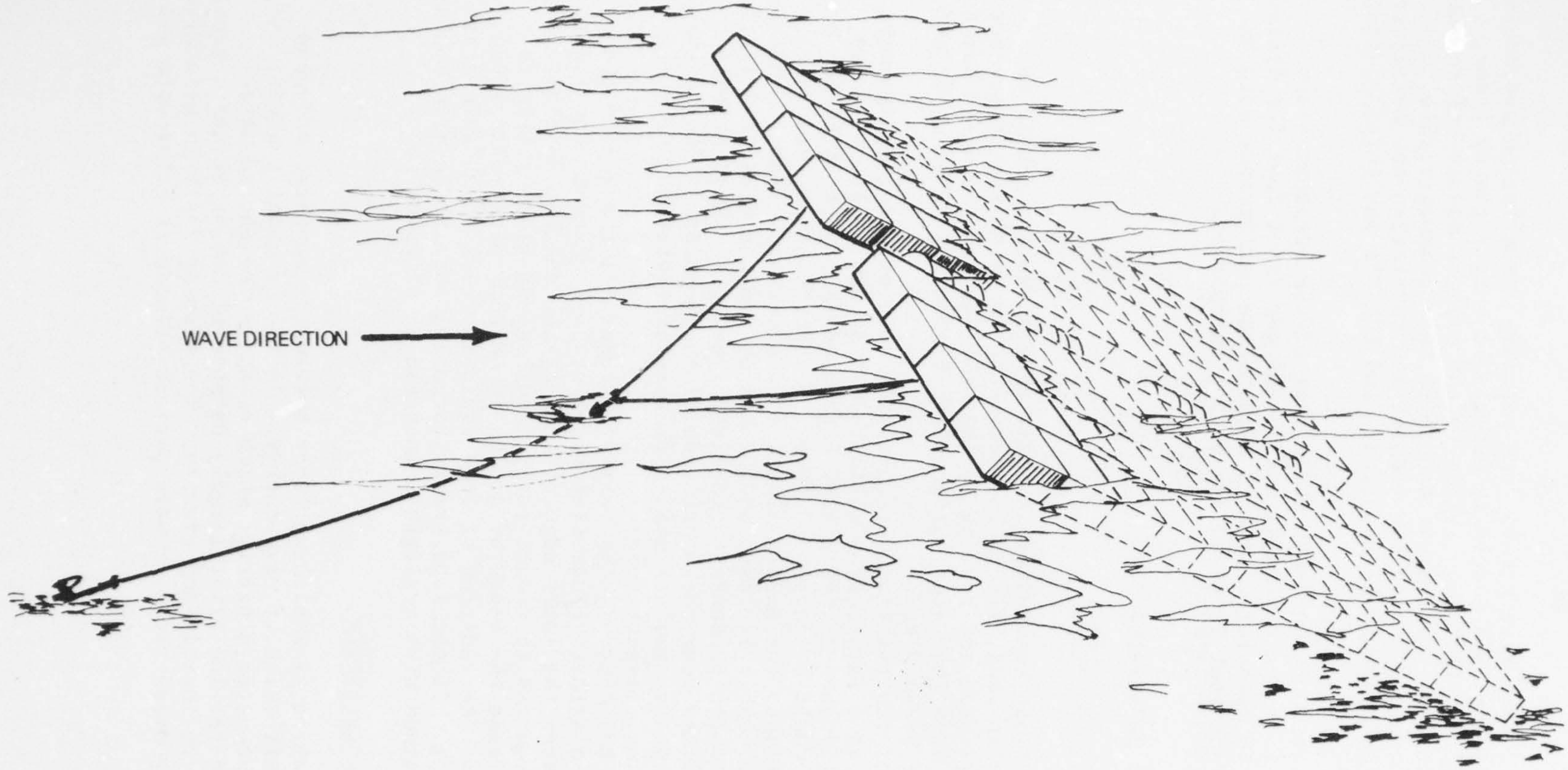


Figure 18. Two modules of a sloping float breakwater.

wave energy and because its configuration is such that in its operating range it is relatively inefficient in responding to wave pressures and generating waves on the shoreward side. In the incomplete-barrier version, low-frequency wave energy is transmitted through the opening. The associated decrease in effectiveness would vary with the size of the gap and the spectrum of the incident wave energy.

Depth Limitation

The sloping float breakwater is restricted in use to relatively shallow water because the angle of inclination of the floats must be rather small. The maximum depth of water is determined by the maximum acceptable length of the floats and legs, together with the maximum angle that results in acceptable performance. The laboratory experiments on performance (Ref. 3), which covered only legless floats, did not clearly define the maximum acceptable angle; possibly it is as great as 30 degrees. For illustration, if the sloping float were 120 feet long, the maximum allowable angle 25 degrees, and the mean freeboard 6 feet, the maximum depth would be 45 feet. This 120-foot sloping float module could be made up of a 90-foot NL pontoon section with 30-foot legs added.

Performance Summary

Figures 19 and 20 summarize the performance predicted for solid (legless) sloping float breakwaters in fully developed, local-wind-generated seas, as represented by the Pierson-Moskowitz spectrum.* Figures 19 and 20 are derived from Figures F-2 and F-3, respectively. These graphs show the length of float required to reduce wave heights to levels associated with sea state 3. For example, for a spectrum peaked at 7 seconds and for a water depth of 30 feet, Figure 19 shows that the significant wave height is reduced to 4 feet if the floats are 76 feet long, or to 3 feet if the floats are 98 feet long. By interpolation in Figure 19 or by reference to Figure F-2, it is seen that a 7-second breakwater in a 30-foot depth would have 93-foot floats. Similarly, with reference to Figure 20 or Figure F-3, a 7-second breakwater in 45-foot depth would have 106-foot floats. The performance of these two 7-second breakwaters for other values of the spectral-peak wave period is given in Table 5.

No data are available on the performance of legged sloping float modules. Preliminary experimental data for a pivoting (hinged) sloping float with the height of the gap beneath the float equal to 30% of the depth (see Appendix F) suggest that floats which are 90 and 120 feet long and equipped with legs would function as 7-second breakwaters in water depths up to 40 and 60 feet, respectively.

*The basic performance data are presented in Appendix F.

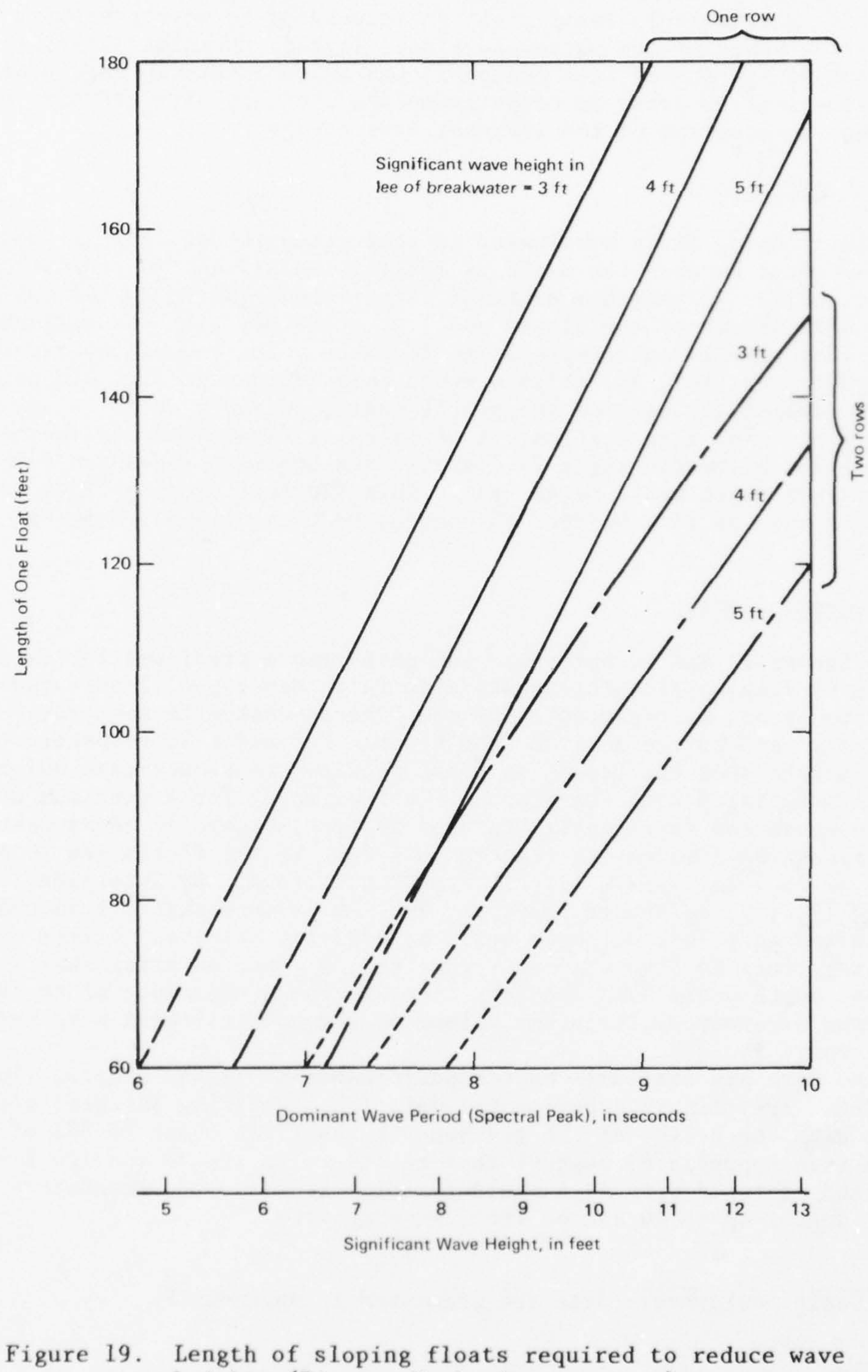


Figure 19. Length of sloping floats required to reduce wave heights (Pierson-Moskowitz spectrum) to sea state 3 levels; depth of water, 30 feet.

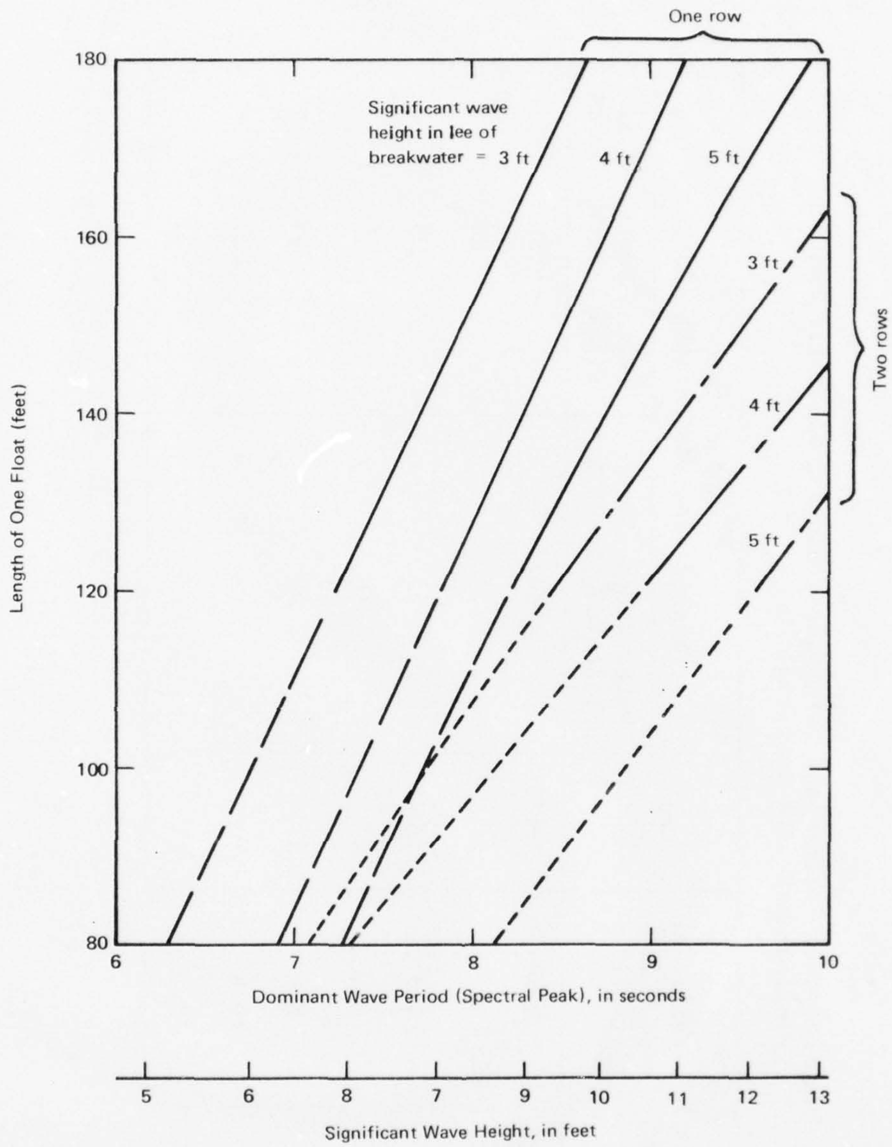


Figure 20. Length of sloping floats required to reduce wave heights (Pierson-Moskowitz spectrum) to sea state 3 levels; depth of water, 45 feet.

Table 5. Predicted Performance For Legless Sloping Float Breakwaters (Pierson-Moskowitz Spectrum)

Peak Period of the Incident Wave Spectrum (sec)	Significant Wave Height (ft)	Sea State	Reduction of Significant Wave Height (%) for –	
			Water Depth, 30 ft Float Length, 93 ft	Water Depth, 45 ft Float Length, 106 ft
4	2.1	2-1/2	90	90
5	3.3	3	78	80
6	4.7	3-1/2	63	65
7	6.4	4	50	50
8	8.4	5	40	35
9	10.6	5	32	27
10	13.1	6	26	21

Pontoon System for Depths Up To 60 Feet

The mass and the shipping cube of a sloping float breakwater are strongly dependent upon one property of the breakwater - the float length, which must be selected on the basis of water depth. To eliminate concern about a large number of float sizes, it is desirable to consider a system constructed from two or three standard module designs. The following set of standard module designs comprise a system expected to yield the specified level of effectiveness* and to provide incremental capability in terms of the depth of water in which this level of effectiveness is achieved. Figure 21 is provided for illustration.

Design S1: 90-Foot Float Without Legs. This design produces the specified wave height reduction if the depth is about 30 feet or less. A specific design may be obtained quickly by adapting a standard 3x15, 21 by 90 foot, Navy Lightered (NL) pontoon barge or causeway section. Another possibility is a 28 by 90-foot Ammi pontoon. Little engineering development is required for the adaptations. Full-scale operational tests and performance verification through model tests are advisable.

In the Performance Summary section, it was noted that legless floats about 15 feet longer than the S1 floats would provide the specified performance in water as deep as 45 feet. Simple floats, 105 feet long (for example, 6x18 NL pontoon barges), or even longer floats, could be practical if ship transportation is not needed; stacked and lashed together, they could be transported by towing. However, simple floats longer than 90 feet are not considered further because of present emphasis on ship transportability.

Design S2: 90-Foot Float With Legs. The addition of 30-foot legs to a 90-foot float is expected to extend the depth range to about 40 feet and to lessen scour. Figure 21 shows two designs. In design S2a, the legs are retractable; they are extended for installation but retracted for shipment, making the shipping cube the same as for design S1. In design S2b, the legs are fixed and the module is broken down or folded into two 60-foot lengths for shipment. This design permits more options for shipment than S2a. For S2a, engineering development would involve design of retractable legs; for S2b, design of fixed legs and an efficient technique for breaking or folding the float for shipment would be required.

Design S3: 120-Foot Float With Legs. Design S3 incorporates both retractable legs (as in S2a) and a two-part float (as in S2b) in order to increase the depth range further, to about 60 feet. The space requirement for shipping is the same as for design S2b. The major items of engineering development are the retractable legs and the connection between the two parts of the float.

*Fifty percent reduction of the significant wave height for a Pierson-Moskowitz spectrum with 7-second peak period.

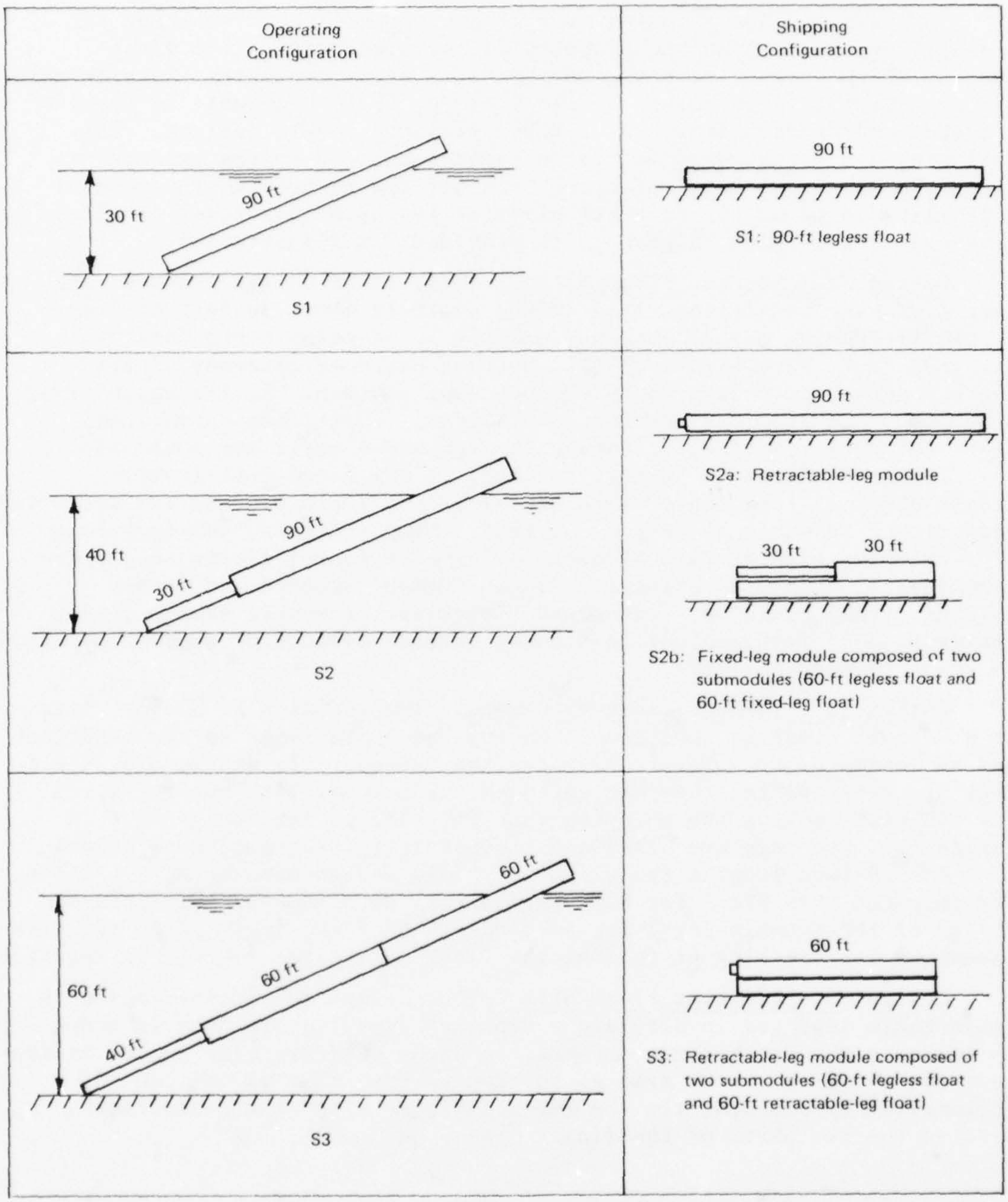


Figure 21. Sloping float breakwater: proposed standard module designs.

Incremental Capability of the System. Successive development of the three designs would represent a progressive increase in capability and transportability. Advance from S1 to S2a, involving the addition of retractable legs, should increase the operating depth from about 30 feet to about 40 feet without decreasing transportability. Advance from S2a to S2b, which simplifies the design of the legs but introduces two-part float construction for shipping, would maintain the same capability and increase significantly the number of lineal feet of breakwater that could be carried on a LASH. Advance from S2b to S3, incorporating both retractable legs and two-part float construction, should increase the operating depth to about 60 feet without decreasing transportability.

Naturally, the logistic burden is clearest for design S1, which would be developed first to prove the concept and provide initial capability quickly. Tests may show that a legged float is preferable; S1 would then be replaced by S2.

Design Features For S1

Design S1 would be adapted from a 3x15 NL pontoon barge or causeway section. The Ammi pontoon appears to be a better structure from the standpoint of rigidity and suitability for conversion of an existing design, but it is not readily available. The P-series pontoon structures are more available and are fairly rugged. Design modifications could be incorporated into new constructions.

In addition to mooring attachments, a ballasting system must be added to a 3x15 pontoon structure. The ballasting system illustrated in Figure 22 consists of openings in the bottom and top sides of the individual pontoons. The openings in the top are connected through manifold piping to a single venting valve in the manifold header at one end of the structure. The valve would also be used to admit air under pressure, to deballast and refloat the module. Penetrations are needed only in two-thirds of the pontoons. Exposed piping is the simplest for converting an existing pontoon. Even though the piping is on the lee side, a more protected arrangement may be desirable for new construction.

In operation, floats would be moored in pairs or in fours (see Figure 23), depending partly upon the mooring load. There are no data on mooring loads; however, observations of the legless float in the laboratory tests indicated that the loads may be relatively light (Ref. 3).

Figure 23 shows an installation for 30-foot depth. The twenty-four 21 by 90-foot modules comprise a 7-second breakwater with an axial length of 590 feet and an effective length (see Appendix E) of 540 feet.

Logistic Aspects - Summary

The following paragraphs summarize material in Appendix F.

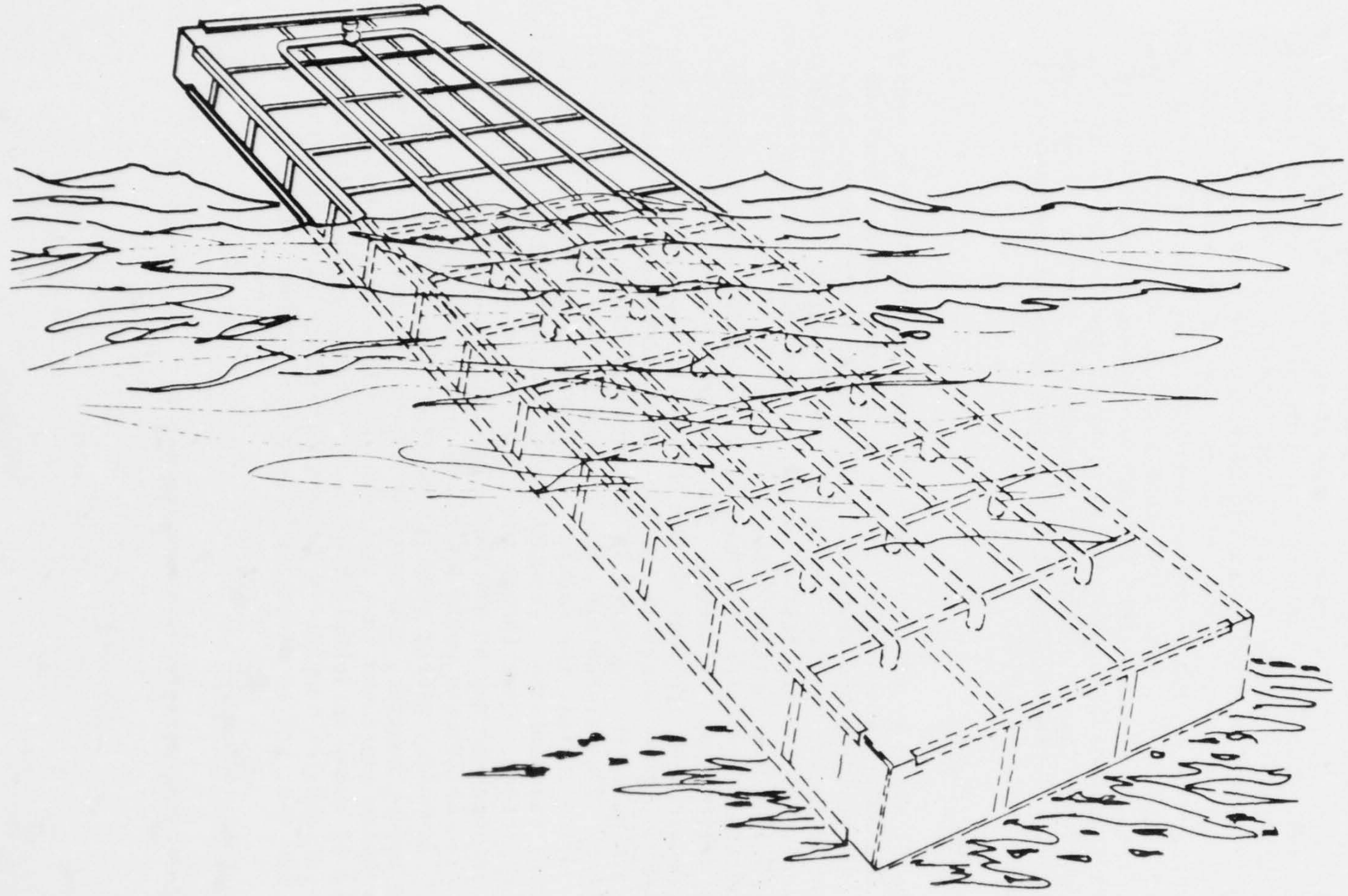


Figure 22. Pipe manifold for ballasting and deballasting [illegible] pontoon structures.

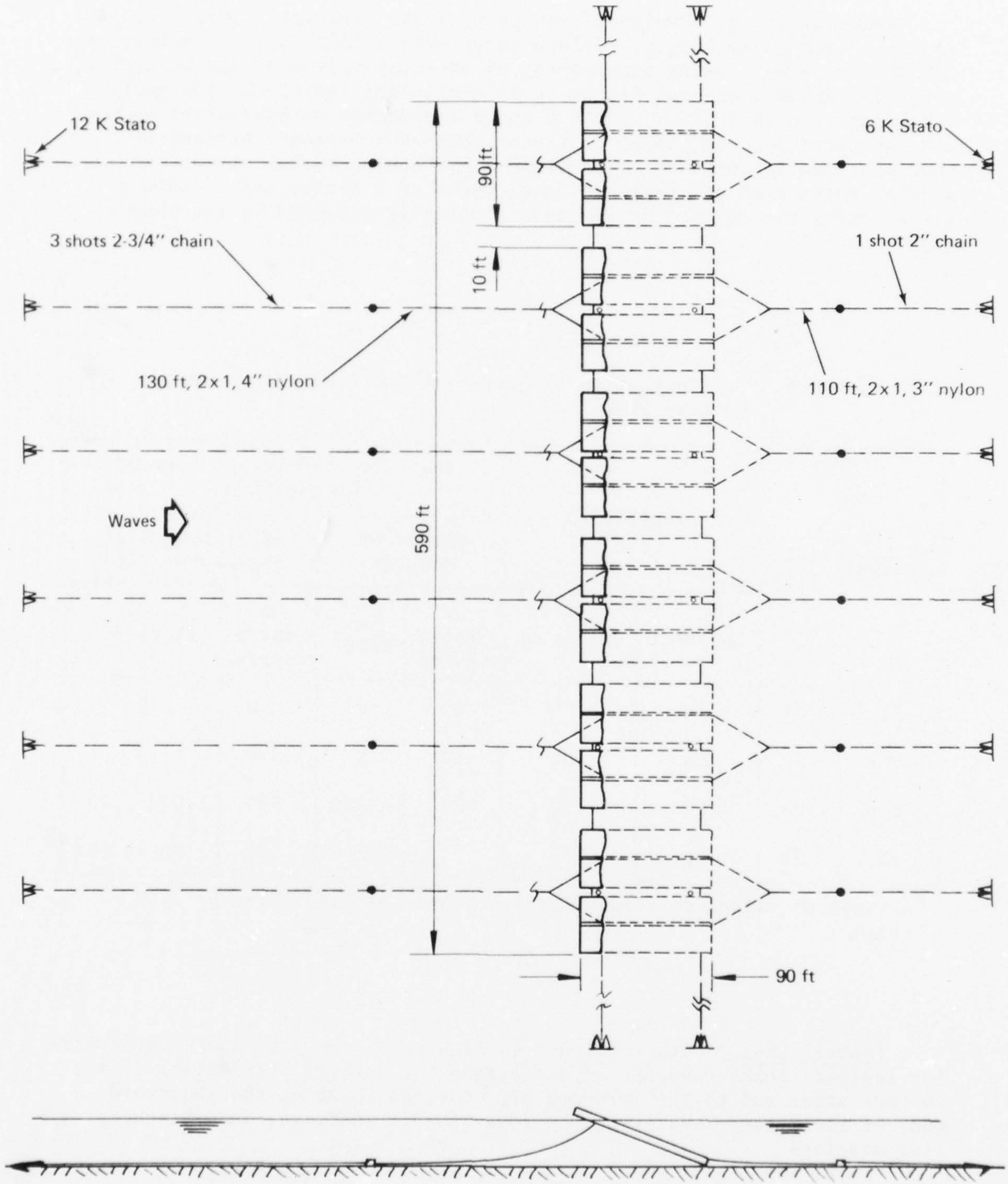


Figure 23. Sloping float breakwater design S1 in 30-foot depth.

Transportation. Overseas transport of the breakwater modules would require ocean-going barges, certain ships with well decks, or bargeships (SEABEE or LASH). Barge transportation is relatively slow and well-deck ships and SEABEEs are not likely to be available; therefore, the most likely carrier is a LASH. Table 6 shows the number of breakwater modules and the corresponding number of lineal feet of a 7-second breakwater that one LASH could carry. The figures pertaining to the stowage of modules below deck are based on development of a design and technique for stacking the modules in the spaces normally occupied by the ship's lighters.

Table 6. Transportation of Sloping Float Breakwater Modules on LASH Ships

Design	Width (ft)	Length (ft)		Quantity of Material Carried On One Ship			
				Number of Modules		Axial Length of Breakwater (ft)	
		Shipment	Operation	On Hatch Covers	In Hold[a]	On Hatch Covers	In Hold[a]
S1	21	90	90	30	0	750	0
S2a	28	90	120	30	0	1,000	0
S2b	28	60	120	21	49-89	700	1,600-2,900
S3	28	60	160	21	49-89	700	1,600-2,900

[a]A range of values corresponds to the range of capacities of LASH ships.

Installation. With reference to Figure 23, the anticipated procedure for legless floats consists of presetting the anchors, connecting floats to each other and to the fore and aft moorings, sinking the shoreward ends of the floats, adjusting the fore and aft moorings, and attaching side moorings.

For designs S1 and S2a, the installation rate for a short breakwater is estimated to be about 200 ft/day, based on 12-hour days; this estimate includes the setting of anchors. Three vessels would be required: a warping tug, an ARS, ATF, or ATS, and a 3,000- to 5,000-hp tug. Use of the warping tug would introduce the only drain on amphibious construction assets. For designs S2b and S3, the required installation time is estimated to be 33% to 50% greater.

Cost. The fabricated cost for design S1 is estimated to be about $3,400 per front foot, including the incorporation of design modifications into new construction. Very rough estimates for designs S2 and S3 are $5,200 and $6,800 per front foot, respectively.

SPECIFIC CONFIGURATIONS FOR COTS BREAKWATERS

Cargo Vessel Anchorage

A fixed, ribbon-type breakwater is assumed. It should suit every cargo ship; therefore, its length is based on a ship 900 feet long. The depth of water at the location of the ship is not fixed; however, it would normally be between 50 and 100 feet. Therefore, the depth at the location of the breakwater is likely to be at least 60 feet, and the use of any of the sloping float designs is apparently precluded. Of the tethered float designs, T1 is evidently the one best suited to this application. Design T2 appears to require excessive installation time if LASH-carried. A bottom-resting version of design T1, which would be similar to T3 but which would probably have the large, light-weight floats of T1, could conceivably be used in depths up to 80 feet or more; but, compared to T1, such a design would have certain disadvantages. The weight of ballast would be greater (roughly twice that of T1, if the principle used to determine the weight of T3 is adopted); greater attention would be required, in determining the site for the breakwater, to unevenness of the bottom and to the tidal range; and a nominal increase in the number of rows of floats to maintain 7-second capability would add to the amount of material.

If the alongshore current is weak, the ship may be moored headed into the waves and the stern and both sides of the ship can be freely worked. If the current is strong, a mooring with the ship's heading parallel to the breakwater axis may be required. Some idea of when the current is the dominant force on the ship may be gained by reference to Appendix B, where results of some preliminary calculations for a smaller, swing-moored ship showed that the current (if greater than about 2 knots) is the dominant force in controlling the ship's heading. If the ship is not allowed to swing, the force of the current could be very large. The problem of determining the maximum tolerable force has several facets, one of which is anchor capacity. Data on the drag characteristics of hulls indicate that, if a C8 containership mooring has two mooring legs directly abeam, with 380-kip anchors, the strength of a beam-on current should not be greater than about 1.5 knots.

Weak-Current Case. The configuration of the breakwater is shown in Figure 11; the orientation of the ship in Figure 15. An effective length of breakwater of 1,340 feet is required on the basis of a distance of 150 feet between the ship's stern and the edge of the wave window. Other T1 breakwater properties would be as follows:

Property	Measurement
Actual length	1,790 ft
Beam	750 ft
Number of moored elements	15
Cost	$9,600,000
Installation time	8-1/2 days

Strong-Current Case. The mooring for the breakwater would be similar to that in Figure 16. For 200-foot separation of ship and breakwater and 200 feet of sheltered area astern for bargeships, the required effective length of the breakwater is about 1,300 feet. Therefore, the actual length and other breakwater properties would be identical to those for the weak-current case.

Combined Current, Wind, and Waves. The moorings in the foregoing two examples would not be feasible for many combinations of high winds, high or long waves, and a strong current, owing to the magnitude of the mooring force. Although no design has been worked out, a mooring that permits the ship to swing over an arc restricted to 180 degrees would be more versatile and would require fewer components and probably less installation time than would a mooring for a fixed heading. To protect lighters and platforms at the sides of a swing-moored ship, the breakwater would have to be about 3,000 feet long* if both sides of the ship must be worked – and therefore sheltered – at all times. However, if only one side of the ship is worked,** the required length of the breakwater would be as noted above for a fixed heading – about 1,800 feet. At one end of the ship's 180-degree range of headings, the platform or lighter would be on the seaward side of the ship but behind the breakwater. When the ship has swung around 180 degrees, it would lie beyond the end of the breakwater; but the platform or lighter would be on the shoreward side of the ship and therefore in a sheltered area. At intermediate positions, either the breakwater or the ship would provide shelter.

Cargo Discharge Facility (Barge Unstuffing)

The depth of water at the breakwater could vary from 20 to 60 feet or more. No one breakwater is feasible for this entire range of depths; therefore, the selection of one breakwater design puts a restriction on the location of the facility. For planning, designs S1, S2, and S3

*Four thousand feet for 360-degree swing.

**This concept could apply to a RO/RO ship having ports on one side only.

should not be considered for depths greater than about 30, 40, and 60 feet, respectively, to insure that the specified level of effectiveness is obtained. Similarly, design T1 should not be considered in planning for depths less than 35 to 40 feet to insure that performance and clearance beneath the ballast are not compromised. For design T3, data on performance over a range of depths are required to ascertain what limits there may be on the operating depth.

To accommodate operations with a four-section causeway, the effective length of the breakwater should be about 550 feet. Other properties of breakwaters for this application are as follows:

Property	T1	S3	S2	S1
Actual length	1,070 ft	700 ft	630 ft	620 ft
Beam	750 ft	160 ft	120 ft	90 ft
Number of moored elements	9	-	-	-
Number of floats	-	20	18	24
Cost	$5,700,000	$4,700,000	$3,400,000	$2,100,000
Installation time	5-1/2 days	5 days	4 days	3 days
Depth limitation	>35 ft	<60 ft	<40 ft	<30 ft

Barge Marshalling Area

The depth of water at a breakwater for the barge marshalling area would probably range from 30 to 60 feet. Determining the minimum must take into account the sea-to-shore expanse of the marshalling area. Applicable designs apparently are T1, T3, S2, and S3. The length of the breakwater depends upon the mooring plan, which has not been firmly established. Preliminary estimates are that, for 80 barges, the breakwater length would be from 2,500 to 3,500 feet long.

Elevated Causeway

The depth of water at the shoreward edge of the breakwater may vary from 15 to 32 feet. This range of values is derived from the range of depth used for the causeway development and from values of the bottom slope ranging from 1:30 to 1:120 (see Figure 4). An effective length of breakwater of at least 600 feet is required.

Breakwater designs T3, S2, and S1 are applicable. The following table shows properties of S2 and S1 breakwaters for the elevated causeway. Design T3 is excluded because performance data needed to determine beam dimensions for the depths in question have not been reported.

Property	S2	S1
Actual length	700 ft	660 ft
Beam	120 ft	90 ft
Number of floats	20	26
Cost	$3,600,000	$2,200,000
Installation time	4-1/2 days	3 days
Maximum depth at toe of breakwater	40 ft	30 ft

CONCLUSIONS

1. COTS can benefit from the use of transportable breakwaters. The specific benefit most clearly defined is reduction in the frequency and duration of occasions when cargo transfers to and from lighters and barges would be slowed or even interrupted by wave action. Another potential benefit is protection for barges stored (moored) in a barge marshalling area. For the latter application, breakwater performance requirements have not been clearly defined.

2. Transportable breakwaters to reduce wave heights to sea state 3 levels when the incident waves range in height up to about 10 feet while the dominant (spectral peak) wave period ranges up to about 7 seconds are feasible; that is, it appears possible to transport breakwaters of the necessary size overseas and install them in reasonable time and without extreme requirements on ships and construction equipment. It will be noted that transportation requirements vary significantly with the design of the module.

3. The stated breakwater capability (reduction of 50% or more in the significant wave height for dominant wave periods up to 7 seconds) is sufficient to reduce considerably the liveliness of small, moored crane-platforms, lighters, and barges engaged in the transfer of cargo at the cargo ship anchorage, the cargo discharge facility (barge unstuffing operations), and the elevated causeway.

4. Breakwaters designed to provide the same wave height reduction when the dominant wave period is greater than 7 seconds would provide additional benefit but would impose a greater logistic burden. The converse is also true. An analysis of the sensitivity of cargo transfer operations to variations of wave height and wave period will be needed to verify that 7 seconds is the optimum design wave period for the breakwaters. A change from 7 seconds as small as 1 second in the design wave period is logistically significant, resulting in a 40% to 50% change in the number of rows in the floating tethered float breakwater and a 15% to 20% change in the length of the floats of the legless sloping float breakwater.

5. This study indicates that logistic evaluations must deal with breakwater designs - not breakwater concepts. Both the tethered float and the sloping float concepts can be developed into various specific designs which may differ considerably with respect to one logistic criterion or another.

6. A significant result of this study is that no one breakwater design among those considered can satisfy all the needs in COTS for a 7-second breakwater because of limits on the depth of water in which the various breakwaters can be installed and restrictions on the location of some of the COTS components.

7. The floating tethered float breakwater design T1 is the design best suited for installation at the ship unloading area. Other tethered float designs are logistically inferior, and the sloping float designs are probably limited to applications in water shallower than 60 feet.

8. The breakwater for the ship unloading area poses a greater logistics problem than breakwaters for the other points in the COTS system because of the design and the length required. Transportation, in particular, is a critical issue. Almost all the capacity of a C9 LASH - the ship best suited for transporting this breakwater - is required to carry the minimum length of this breakwater (1,800 feet).

9. The length of a breakwater for the barge marshalling area apparently would be comparable to that for the ship unloading area. However, the marshalling area can be located in shallower water, where it may be possible to develop logistically advantageous breakwater designs. Specifically, legged versions of the sloping float concept, the most "transportable" of the designs examined, could provide the capability noted in paragraph 3. The effective length of these advanced designs (S2b and S3) that a LASH could accommodate would be about 2-1/2 times that of the tethered float design T1. Stowage in the hold of a LASH is assumed for all three designs.

10. Other uses for a transportable breakwater in COTS are in shallow water, and the length of these breakwaters would not be very great - about 700 feet. These uses would be to shelter operations at the elevated causeway and at a moored platform-mounted crane employed to unstuff LASH barges. A C9 LASH apparently could carry these breakwaters and one for the marshalling area if the length of the latter does not exceed 2,200 feet and if sloping float design S2b or S3 is developed and utilized.

11. Areas of potential use in COTS for the bottom-resting tethered float breakwater design T3 are the barge marshalling area, the cargo discharge facility (barge unstuffing), and the elevated causeway. Performance data of the scope required to assess the logistic burden of this breakwater in these applications have not been reported.

ACKNOWLEDGMENTS

Numerous improvements in this technical note resulted from discussions with Mr. Robert J. Taylor, who also worked out the mooring plans and installation schedules. Mr. Hugo Conti programmed the analysis of ship heading in Appendix B. Dr. R. J. Seymour of the California Department of Navigation and Ocean Development provided useful review comments on an early draft (Ref. 23). Mr. Robert Watts of the Naval Ocean Systems Center provided information on the bottom-resting tethered float breakwater.

REFERENCES

1. Naval Facilities Engineering Command. Program plan for container off-loading and transfer system (COTS). Washington, D.C., Apr 1977.

2. ___________. PTA No. 41: Proposed technical approaches for portable port. Washington, D.C., Feb 1969.

3. University of California, Institute of Engineering Research. Report 3-332: Model study of amphibious breakwaters, by D. A. Patrick. Berkeley, Calif., Oct 1951.

4. R. J. Seymour and J. D. Isaacs. "Tethered float breakwaters," paper presented at 1974 Floating Breakwaters Conference, Newport, R.I., 23-25 Apr 1974. Narragansett, R.I., University of Rhode Island, 1974, pp 55-72. (Marine Technical Report Series No. 24)

5. M. E. Essoglou, R. J. Seymour, and J. B. Berkley. "TFB: A transportable open ocean breakwater," in Ocean 75 Record (Proceedings of Combined 1975 IEEE Conference on Engineering in the Ocean Environment and the Eleventh Annual Meeting of the Marine Technology Society), San Diego, Calif., Sep 1975, pp 723-725.

6. University of California at San Diego, Institute of Marine Resources. IMR Reference 76-4 (Sea Grant Publication No. 46): Performance of tethered float breakwaters in deep ocean waves, by R. J. Seymour. La Jolla, Calif., Jan 1976.

7. Civil Engineering Laboratory. Technical Report R-727: Transportable breakwaters – A survey of concepts, by D. B. Jones. Port Hueneme, Calif., May 1971.

8. C. R. J. Wood. "Phoenix," The Civil Engineer in War, volume 2: Docks and Harbours. London, England, Institution of Civil Engineers, 1948, pp 336-368.

9. FMC Corporation. Dynamic breakwater systems. San Jose, Calif., 1972.

10. University of California, Institute of Engineering Research, Wave Research Laboratory. Technical Report 104-9: Wave dissipation by compressed air (pneumatic breakwater), by S. I. Radionov (translation by H. Arnesen). Berkeley, Calif., Apr 1960.

11. R. Lochner, O. Faber, and W. G. Penney. "The 'Bombardon' floating breakwater," The Civil Engineer in War, volume 2: Docks and Harbours. London, England, Institution of Civil Engineers, 1948, pp 256-290.

12. University of Minnesota, St. Anthony Falls Hydraulic Laboratory. Technical Paper No. 31, Series B: An experimental study of flexible floating breakwaters, by J. F. Ripken. Minneapolis, Minn., Oct 1960.

13. M. G. Spangler. "Pontoon break-water," Navy Civil Engineer Corps Bulletin, vol 2, no. 14, Jan 1948, pp 10-13.

14. Queen's University, Department of Civil Engineering. Report No. 60: On floating breakwaters, by A. O. Ofuya. Kingston, Ont., Canada, Nov 1968.

15. The Tethered Float Breakwater Ocean Experiment. The status of the tethered float breakwater development program. La Jolla, Calif., University of California at San Diego, Jan 1977.

16. Moffatt and Nichol, Engineers; Ogden Beeman; and International Maritime Associates. Report: Feasibility study to evaluate the commercial market for a tethered float breakwater system. Long Beach, Calif., Mar 1977.

17. Department of the Navy, Supervisor of Shipbuilding, Conversion and Repair. Technical Report No. 9-75: Preliminary report of at-sea off-loading concepts for roll on - roll off ships, by J. B. Wagner. San Francisco, Calif., Dec 1975.

18. Civil Engineering Laboratory. Technical Report R-852-I: Container off-loading and transfer system (COTS) - Advanced development tests of elevated causeway system, Volume I: Summary, by R. C. Towne. Port Hueneme, Calif., Mar 1977.

19. The Tethered Float Breakwater Ocean Experiment. Technical Note No. 15: Design report and cost estimate for a dredge protection breakwater for Oregon Inlet, North Carolina, by R. J. Seymour. La Jolla, Calif., University of California at San Diego, Jan 1978.

20. E. J. Buck. "Tethered float breakwater ballast configuration study (preliminary)," enclosure to memorandum dtd 3 Mar 1976 from D. B. Jones

(Civil Engineering Laboratory) to R. J. Seymour (Tethered Float Breakwater Ocean Experiment).

21. F. R. MacLeay. "Thin wall concrete ship construction," Journal of the American Concrete Institute, vol 21, no. 3, Nov 1949, pp 193-204.

22. University of California at San Diego, Institute of Marine Resources. IMR Reference 76-2 (Sea Grant Publication No. 44): Design limits on critical float emergence in a tethered float breakwater, by D. M. Hanes and R. J. Seymour. La Jolla, Calif., Jan 1976.

23. R. J. Seymour letter to D. B. Jones, 10 Nov 1977.

24. Global Marine Development Inc. Report No. RPT-04044-001: Low cost precast concrete ballast structure, Phase 1: Design and analysis. Newport Beach, Calif., Dec 1976.

25. Civil Engineering Laboratory. The behavior of an inclined pontoon breakwater in water waves, by F. Raichlen and J. J. Lee. Port Hueneme, Calif., Jun 1977.

26. W. J. Pierson, Jr., and L. Moskowitz. "A proposed spectral form for fully developed wind seas based on the similarity theory of S. A. Kitaigorodskii," Journal of Geophysical Research, vol 69, no. 24, Dec 1964, pp 5181-5190.

27. H. Rye, R. C. Byrd, and A. Tørum. "Sharply peaked wave energy spectra in the North Sea," in Proceedings of the Sixth Annual Offshore Technology Conference, Houston, Tex., 6-8 May 1974. (Paper No. OTC 2107)

28. T. P. Barnett and K. E. Kenyon. "Recent advances in the study of wind waves," Reports of Progress in Physics, vol. 38, 1975, pp 667-729.

29. Naval Oceanographic Office. Publication No. 603: Practical methods for observing and forecasting ocean waves by means of wave spectra and statistics, by W. J. Pierson, Jr., G. Neumann, and R. W. James. Washington, D.C., 1955.

Appendix A

COTS PROGRAM BACKGROUND*

DOD planning for the logistic support necessary to sustain major contingency operations, including amphibious assault operations and Logistics-Over-the-Shore (LOTS) evolutions, relies extensively on the utilization of U. S. Flag commercial shipping. Since the mid-1960s, commercial shipping has been steadily shifting towards containerships, Roll-On/Roll-Off ships, and bargeships (e.g., LASH, SEABEE). By 1985 as much as 85% of U. S. Flag sealift capacity may be in container-capable ships - mainly non-self-sustaining (NSS) containerships. Such ships cannot operate without extensive port facilities. Amphibious assault and/or LOTS operations are usually conducted over undeveloped beaches, and expeditious response times preclude conventional port development. Handling of containers in this environment presents a serious problem. The problem, as defined above, is addressed in the overall DOD Over-the-Shore Discharge of Containership efforts involving developments by the Army, Navy, and Marine Corps. Guiding policy is documented in the "DOD Project Master Plan for Surface Container Supported Distribution System" and the OASD I&L system definition paper, "Over-the-Shore Discharge of Container Capable Ships (OSDOC) System."

In response to the DOD Master Plan, Navy Operational Requirement OR-YSL03 has been prepared for an integrated Container Off-Loading and Transfer System (COTS) for discharging container capable ships in the absence of port facilities. The COTS Navy Development Concept (NDCP) No. YSL03 was promulgated July 1975 and the Naval Material Command tasked with development. The Naval Facilities Engineering Command has been assigned Principal Development Activity (PDA) with the Naval Sea Systems Command assisting.

The COTS advanced development program includes the ship unloading subsystem, the ship-to-shore subsystem, and common system elements. The ship unloading subsystem includes (a) the development of Temporary Container Discharge Facilities (TCDF) employing merchant ships and/or barges with add-on cranes and support equipment to off-load non-self-sustaining containerships alongside; (b) the development of Crane on Deck (COD) techniques and equipment for direct placement of cranes on the decks of NSS containerships to render them self-sustaining in an expedient manner; (c) the development of equipment and techniques to

*Prepared by Naval Facilities Engineering Command.

off-load RO/RO ships offshore; and (d) the development of interface equipment and techniques to enable ship discharge by helicopters (either existing or projected in other development programs). The ship-to-shore subsystem includes the development of elevated causeways to allow cargo handling over the surfline and development of self-propelled causeways to transport cargo from ships to the shoreside interface. The commonality subsystem includes (a) the development of wave attenuating Tethered Float Breakwaters (TFB) to provide protection to COTS operating elements; (b) the development of special cranes and/or crane systems to compensate for container motion experienced during afloat handling; (c) the development of transportability interface items to enable essential outsize COTS equipment transport on merchant ships – particularly bargeships; and (d) the development of system integration components such as moorings, fendering, communications, and services.

Appendix B

HEADING OF A SWING-MOORED SHIP

The heading taken up by a swing-moored ship depends upon the relative strengths and directions of current, wind, and waves. Figures B-1 through B-6 show the results of computations for a tanker type of ship with the following dimensions: length overall, 678 feet; beam, 95 feet; draft, 36 feet; and freeboard, 37 feet. The computations were also based on wind- and current-drag characteristics for tankers – the only published data in hand. Thus, the ship characteristics, taken collectively, are artificial and constitute, at best, only a first approximation for the case of a heavily loaded containership with a tall deckload.

The computational results are further limited in generality in that the water depth is fixed at 60 feet, the pseudo-steady wave force is assumed to be due to waves represented by the Pierson-Moskowitz wave spectrum, the wind and wave directions are assumed to be the same, and swells are assumed to be absent.

Although limited in applicability, the computations are adequate to investigate trends associated with variations of current strength, wind speed, and wave height. For illustration, Figure B-1 shows that if a wind of 16 knots and waves with a significant height of 5 feet are moving from west to east while a current of 2 knots is flowing from north to south, making a 90-degree clockwise angle from the approach direction of the wind to that of the current, the clockwise angle between the ship's heading and the current is 15 degrees; that is, the heading is 345 degrees. Figure B-2 holds for the same conditions as Figure B-1 except that the wave height is reduced by 50%, as if by a breakwater. For waves approaching practically beam-on, the wave force varies as the square of the wave height. Thus, between Figures B-1 and B-2, there is a 75% reduction of the wave force, with the result that the angle between the ship's heading and the approach direction of the current is reduced to 10 degrees. In either instance, if the strength of the current increases, the vessel becomes even more closely aligned with the current. The dashed portions of the curves indicate conditions for which the wave direction is more than 30 degrees off the beam and the wave force is not considered very accurate.

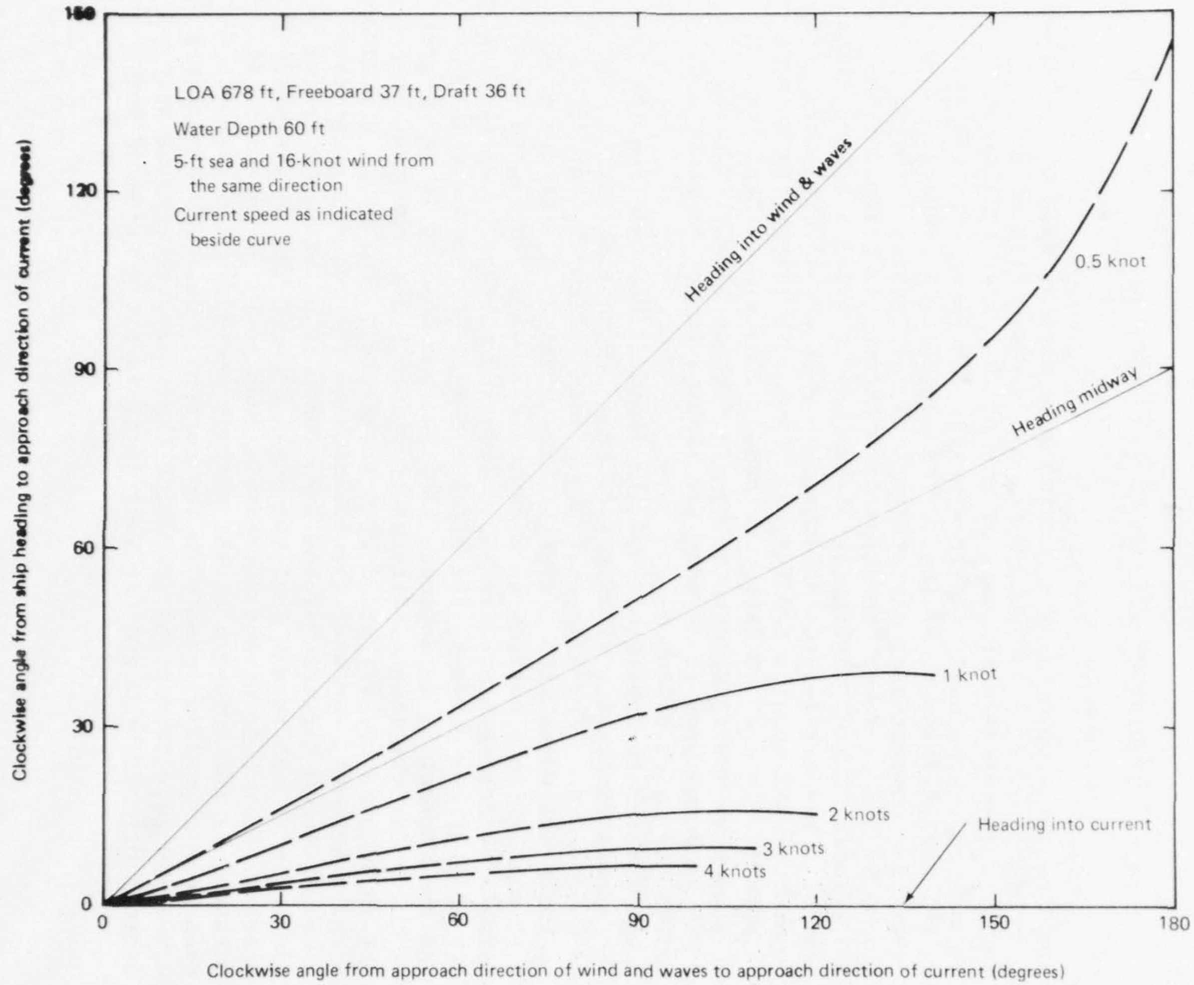


Figure B-1. Swing-moored ship's heading relative to wind, waves, and current; sea state 3 and no breakwater.

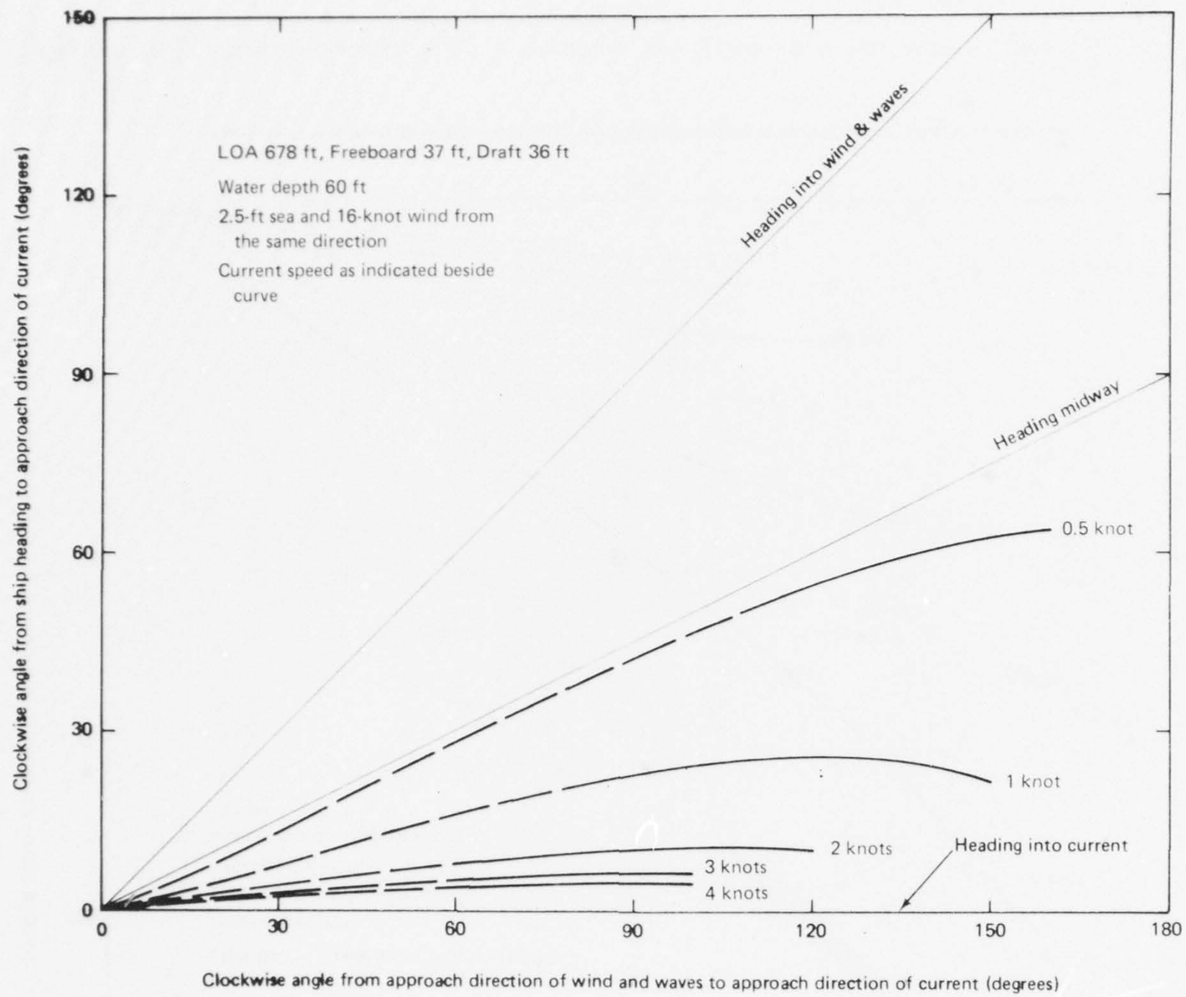


Figure B-2. Swing-moored ship's heading relative to wind, waves, and current; sea state 3 and 50% wave height reduction.

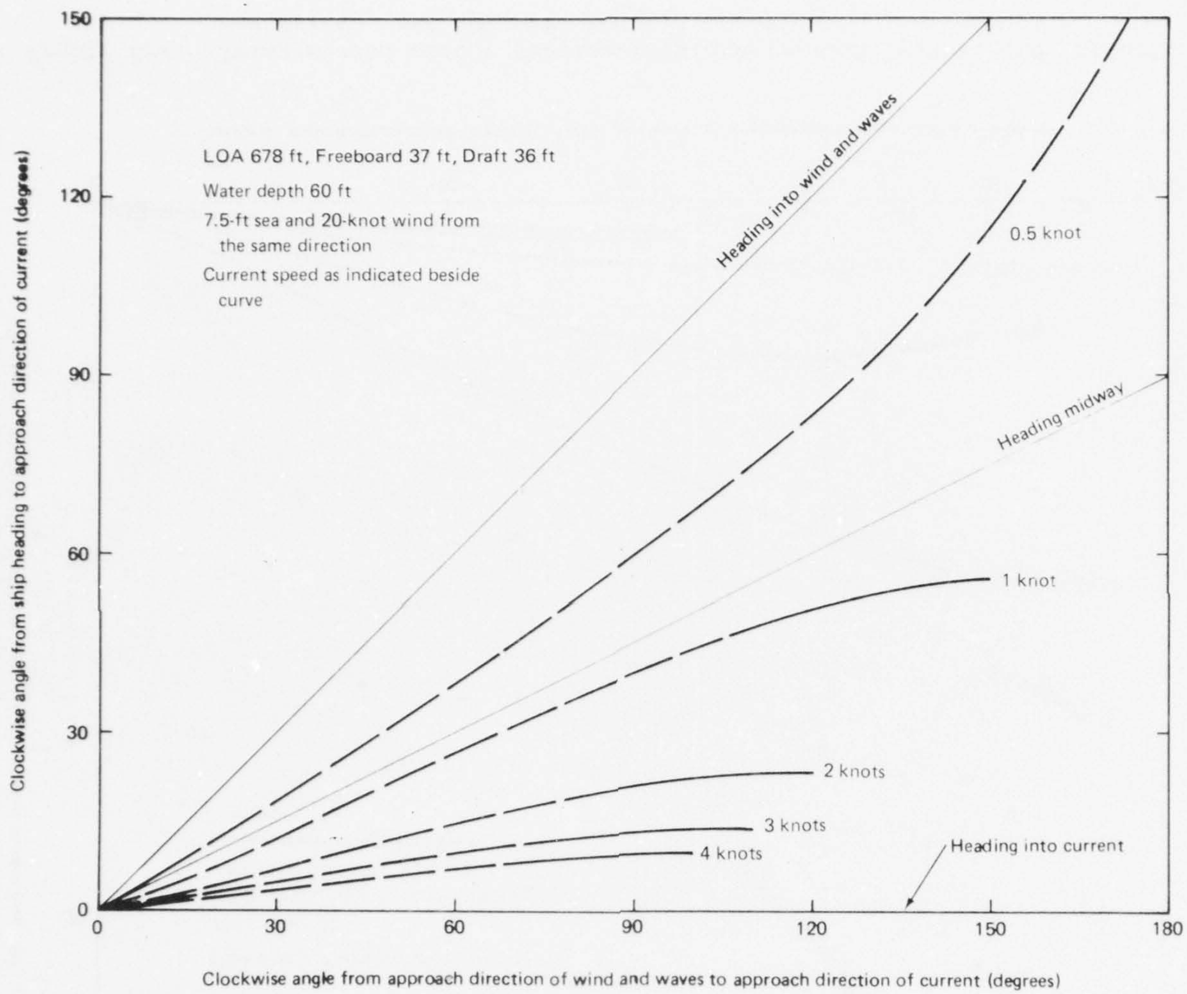


Figure B-3. Swing-moored ship's heading realtive to wind, waves, and current; sea state 4 and no breakwater.

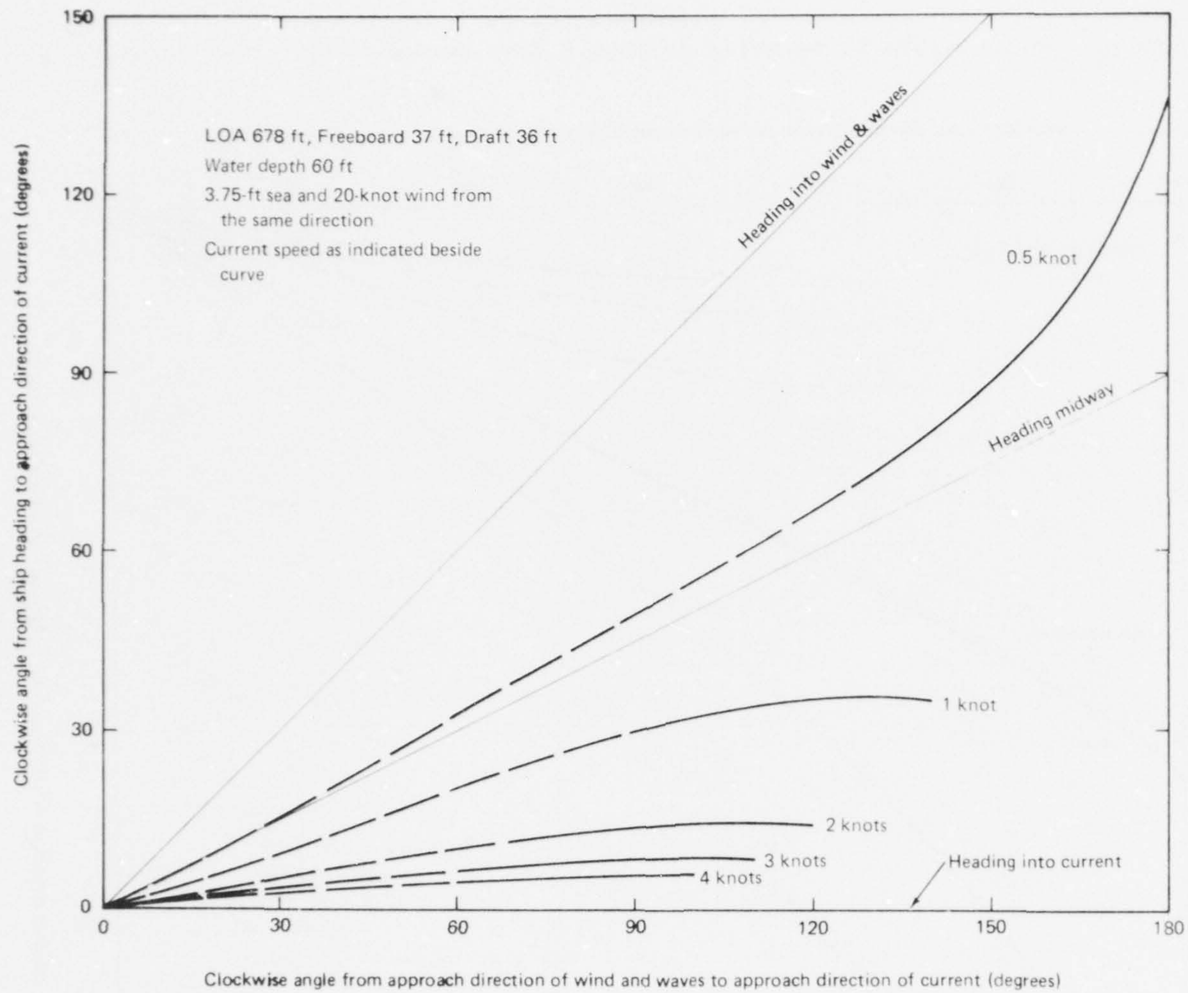


Figure B-4. Swing-moored ship's heading relative to wind, waves, and current; sea state 4 and 50% wave height reduction.

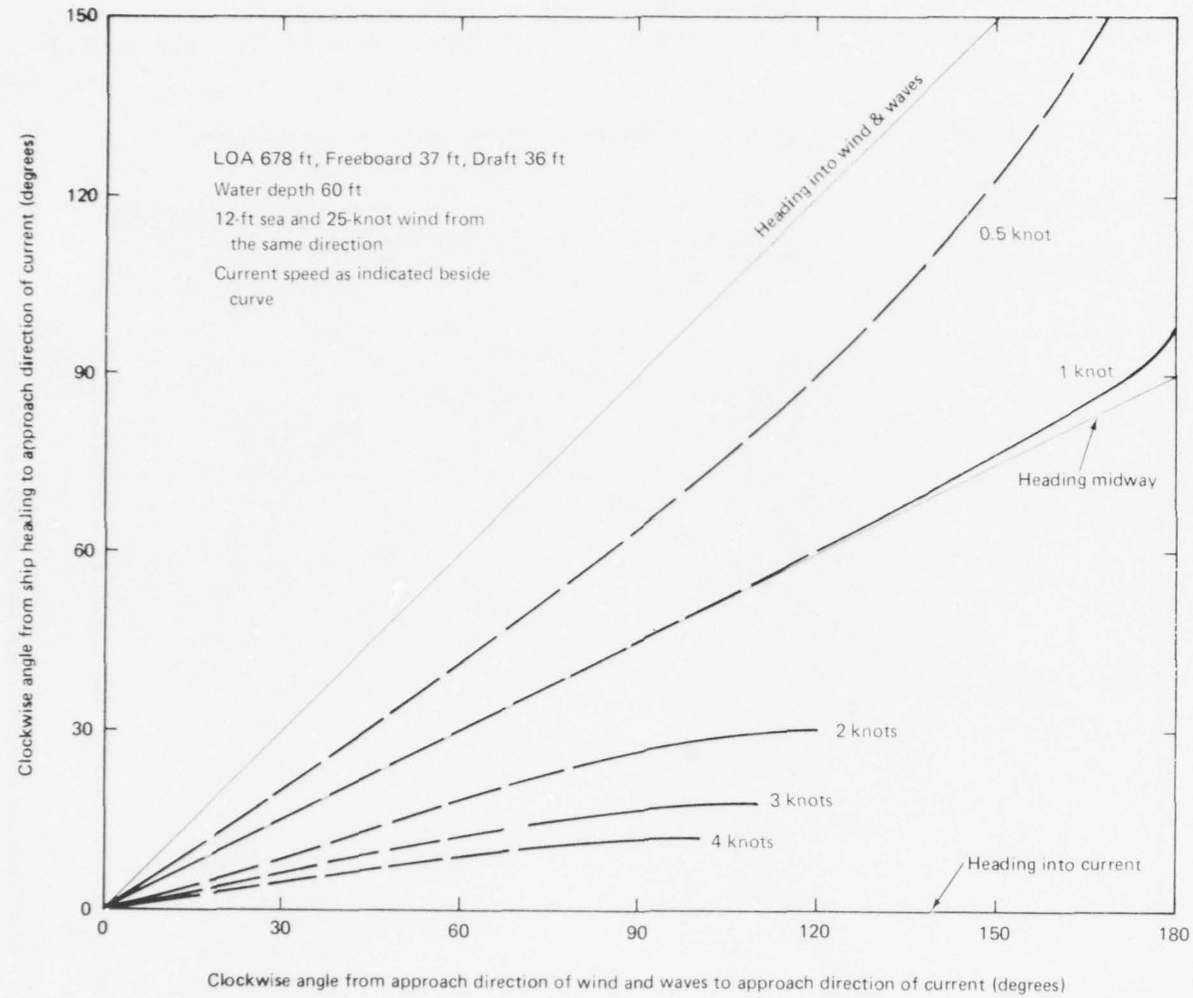


Figure B-5. Swing-moored ship's heading relative to wind, waves, and current; sea state 5 and no breakwater.

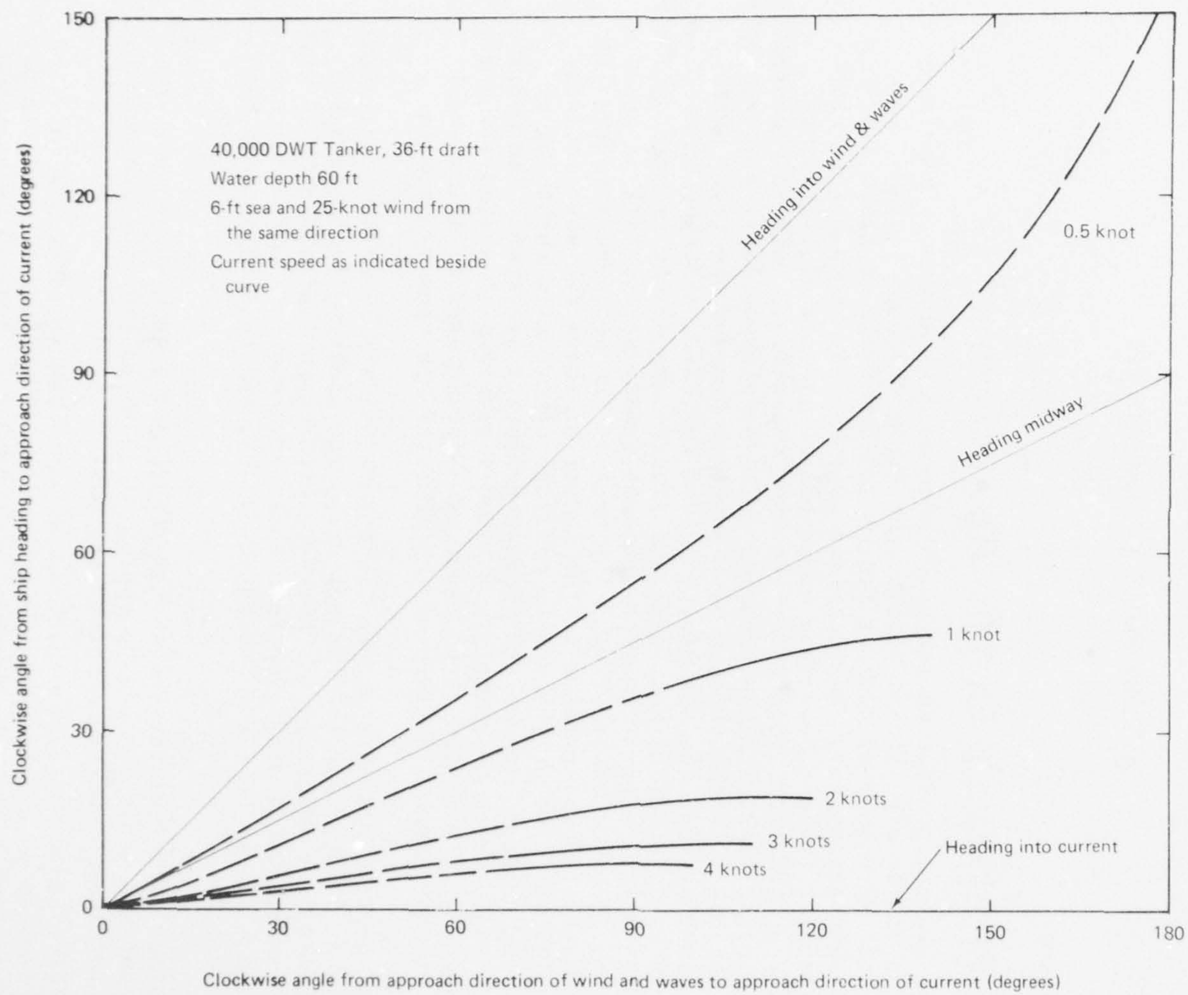


Figure B-6. Swing-moored ship's heading relative to wind, waves, and current; sea state 5 and 50% wave height reduction.

Appendix C

TETHERED FLOAT BREAKWATER DATA

PERFORMANCE

Wave Height Reduction by Deep-Water (Floating) Systems

The general prediction technique presented in Reference 6 relates reduction of the significant wave height, in percent of incident wave height, to the number of rows of floats and the ratio of float diameter to dominant wavelength. The technique applies only to spherical floats of low density (weight less than about 10% of maximum displacement). Reference 6 cites performance for two wave conditions. One is represented by the Pierson-Moskowitz spectrum for fully developed, local-wind-generated seas. The other is represented by a somewhat broader spectrum, which was obtained by reducing the amplitudes of the Pierson-Moskowitz spectrum uniformly by a factor of one-ninth and superposing on the reduced spectrum a Pierson-Moskowitz spectrum with dominant (peak) period half as great as that of the reduced spectrum. The peak of the modified spectrum (the combined spectra) corresponds to the larger of these two wave periods. The significant wave height of the modified spectrum is about 40% of that of the original, unreduced Pierson-Moskowitz spectrum. The modified spectrum was devised to exemplify a bimodal spectrum of a kind which may occur when local-wind-generated waves are superimposed on a low swell from a distant storm. A graph of the modified spectrum appears in Figure D-3.

The performance data graphed in Figure C-1 are specific for a float diameter of 5 feet* and the Pierson-Moskowitz spectrum.** Figure C-1 was derived from Reference 6. However, predictions in Reference 16 with a newer mathematical model indicate that the number of rows predicted in Reference 6 should be increased by about 45%, and this adjustment has been incorporated into Figure C-1.

---

*For other values of the float diameter (D), the required number of rows for 50% reduction can be approximated by multiplying the number of rows obtained from Figure C-1 by the factor $(5/D)^{1.5}$.

**For the Pierson-Moskowitz spectrum, a one-parameter spectrum, a fixed relationship exists between the spectral peak period, T_p, and the significant wave height, H_s (namely, $H_s = 0.13\ T_p^2$ if H_s is in feet and T_p is in seconds). Thus, specification of T_p is also a specification of H_s. This association allows the delineation of sea states on Figure C-1 by means of the shaded areas and sea state code numbers.

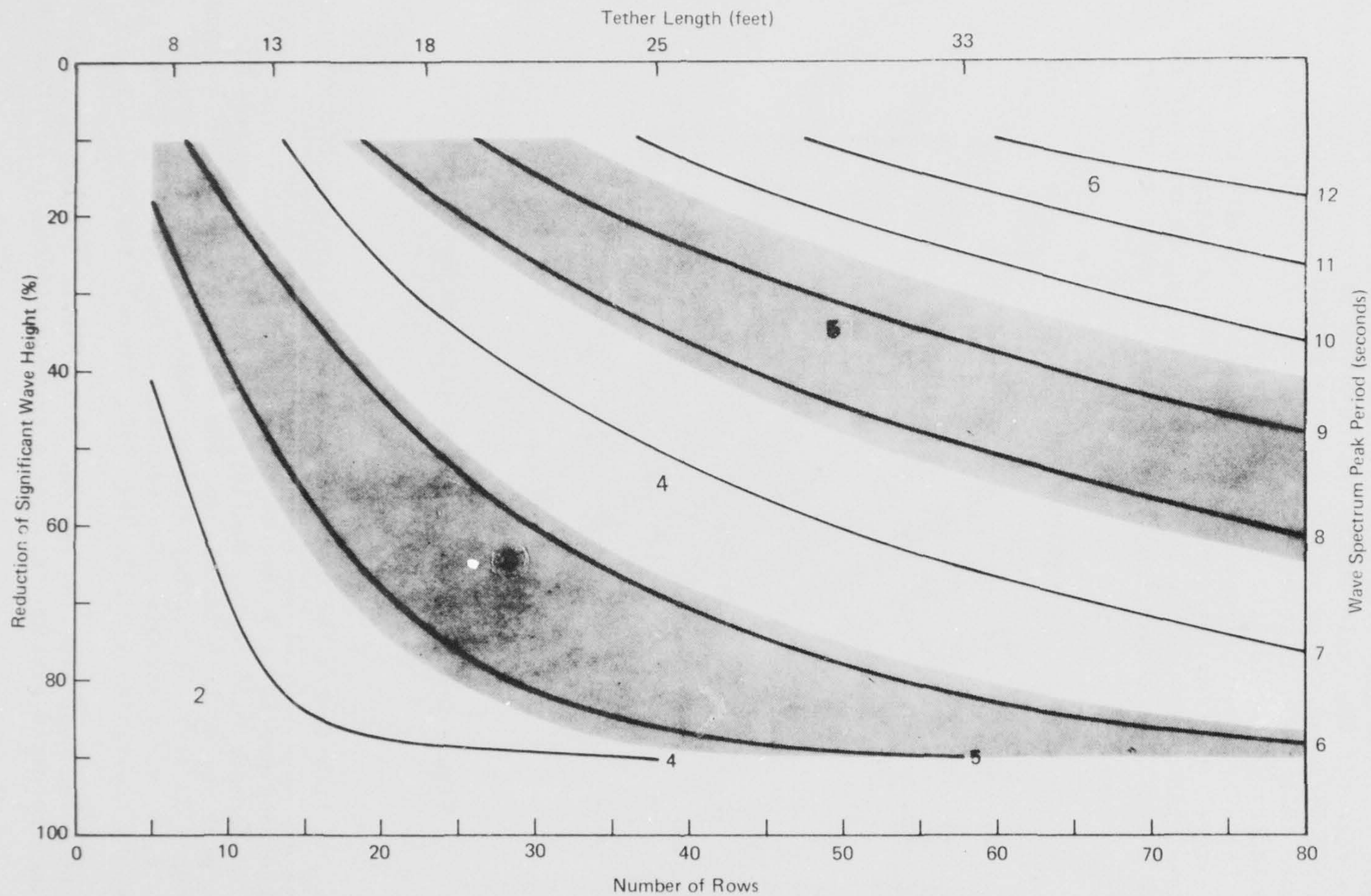


Figure C-1. Tethered float breakwater performance with low-density, spherical floats 5 feet in diameter (Pierson-Moskowitz wave spectrum); number of rows for 50% wave height reduction. (Bold numbers and shading indicate sea states.)

In Figure C-1, the number of rows required for 50% wave height reduction is read off the scale at the bottom below the point of intersection of the 50% line and the curve for the wave period in question. Directly above this point of intersection, the scale at the top shows the optimum tether length for the given wave period.*

Figure C-1 also shows off-optimum performance. Opposite the points where the vertical line for any given tether length intersects the various curves, the corresponding wave height reduction is read off the scale at the left. This tether length is optimum for only one of the wave periods.

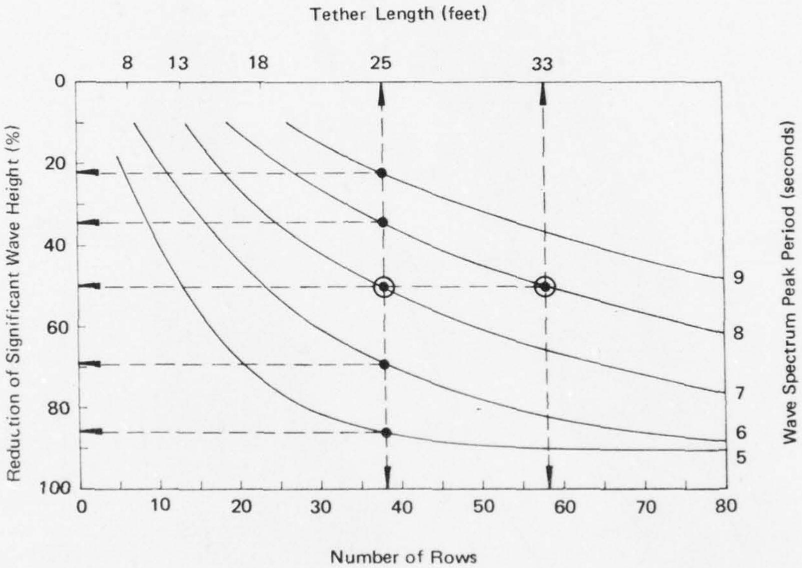


Figure C-2. Performance analysis (examples).

Figure C-2 illustrates the use of Figure C-1. It shows, for example, that 38 rows are required for 50% reduction of the significant wave height if the peak period is 7 seconds and the tether length is the optimum for 7 seconds – 25 feet. Similarly, 50% reduction requires 58 rows if the peak period is 8 seconds and the tether length is the optimum for 8 seconds – 33 feet. For other Pierson-Moskowitz spectra, with peaks at 9, 8, 6, and 5 seconds and a constant tether length of 25 feet, the wave height reductions are 22%, 34%, 69%, and 86%, respectively.

*It should be noted that plotting the curves in Figure C-1 for 4, 5, 6, and 7 seconds required extrapolation of a curve presented in Reference 6.

Figure C-1 and the example of Figure C-2 show the effect on performance of variation of the wave spectrum peak period when the number of rows and the length of the tethers are fixed. The effect of varying the number of rows, with the wave period and tether length fixed, may be estimated (Ref. 6) from

$$C_T^* = (C_o^*)^{n/n_o}$$

in which C_T^* is the wave transmission coefficient defined by

$$C_T^* = 1 - \frac{\text{percent reduction of significant wave height}}{100}$$

n is the variable number of rows, and C_o^* and n_o are corresponding reference values of C_T^* and n, which are taken from Figure C-1 for various pairs of values of the wave period and the tether length. This formula was used to construct Figure C-3. The formula is more accurate the closer n/n_o is to unity.

Effect of Wave Spectrum Breadth on Performance

Reference 6 notes that increased efficiency of tethered floats in deep water is to be expected from increased breadth of the wave spectrum. It also presents a prediction technique for the "modified" spectrum described above, which is broader than the Pierson-Moskowitz spectrum. Performance data for spectra that are more peaked than Pierson-Moskowitz are not available.

The analysis of Reference 6 shows that the number of rows required for 50% reduction of the significant wave height for the modified spectrum is about half the number required for the Pierson-Moskowitz storm spectrum.

LOGISTICS

Design T1

Design T1 consists of 28 spherical floats, 5 feet in diameter, attached to a raftlike or bargelike ballast module of reinforced concrete, 31 by 61 feet in plan (see Figure 10). The ballast and floats would weigh 84 tons.

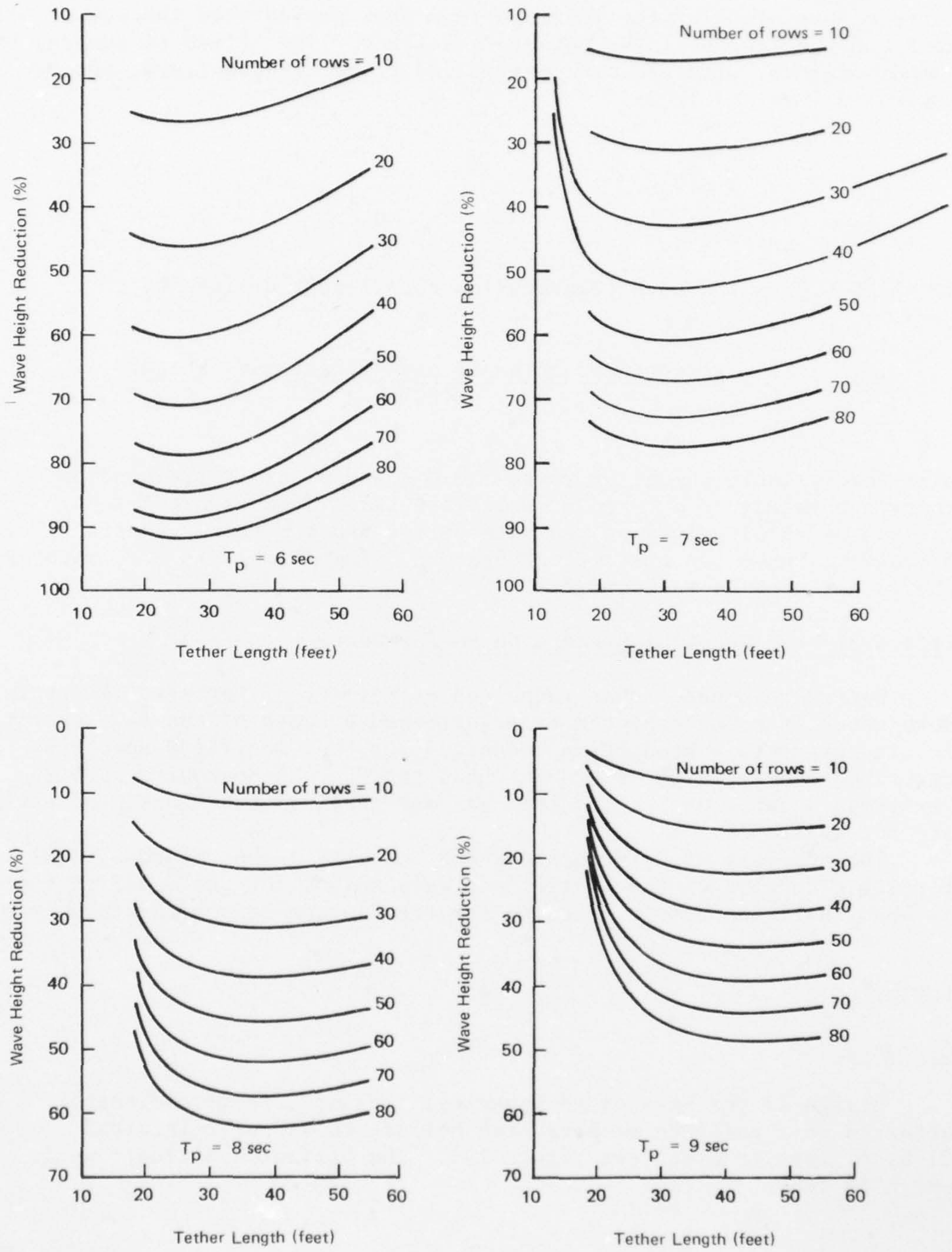


Figure C-3. Tethered float breakwater performance with low-density, spherical floats 5 feet in diameter (Pierson-Moskowitz wave spectrum); effect of variation of number of rows. (T_p is the wave period corresponding to the peak of the spectrum.)

Transportation. For long-distance ocean transportation, the modules could be carried only on large ocean-going barges, on well decks (LSD, LPD, LHA, or TRIMARINER), or on bargeships (LASH or SEABEE). A module with the 31- by 61-foot plan dimensions was selected so that it could be lifted onto a LASH vessel by the ship's gantry crane and stored in the spaces normally used for the ship's barges (lighters). Two modules can be stored in the space occupied by one LASH barge. Thus, one LASH could carry in place of barge cargo 98 to 178 modules, depending upon the particular vessel. An additional 56 to 64 modules could be placed on the hatch covers.

In similar fashion, a larger ballast module could be designed to match the plan dimensions of SEABEE barges for storage in their place, but the larger module would be less versatile. About 134 LASH-sized ballast modules could be carried inside SEABEE barges, but the need for a crane at the destination to extract them is a significant disadvantage. Also, it is unlikely that one of the three SEABEE's in existence would be available for breakwater transport for COTS.

Ships with well decks can accommodate the floating ballast modules, but none can carry very many; and again, none is likely to be available for this purpose.

Ballast modules of LASH-barge size (i.e., 30 by 60 feet) can be carried on a 100- by 400-foot ocean-going barge, with eight layers (108 modules) constituting an average barge load. This mode of transport requires a crane at the destination for unloading. The crane could be part of the cargo of one barge. Unloading by crane appears to be the simplest procedure.

To summarize, Table C-1 shows the number of modules that one vessel could carry. The quantity of breakwater material on the vessel is also expressed in terms of the axial length of a 7-second breakwater (35 rows of floats). A LASH is the best carrier on the basis of capacity and speed, and for COTS it is the only likely carrier on the basis of availability.

Installation. The main steps in installing the configuration of Figure 11 are as follows:

1. Locate and mark positions of forward anchors.

2. Install and set forward anchors; attach buoy and line and drop chain to bottom for later recovery.

3. Install and set (temporarily) the two forward upcurrent anchors directly in line with current.

4. Unload modules and tow them to breakwater site for assembly of moored elements.

5. Attach moored elements progressively downcurrent, using forward and side moorings for stabilization.

6. Attach temporary downcurrent moorings; sink sections while applying lateral load.

7. Place and temporarily set the two rear upcurrent anchors directly in line with the current.

8. Attach rear sections using side moorings and fore-and-aft connecting wires for stabilization.

9. Attach temporary rear downcurrent moorings and sink the rear sections.

10. Sequentially raise and reset the lateral moorings in the required final orientation, beginning upcurrent (shoreward, then seaward) and ending downcurrent (shoreward, then seaward) to pull the breakwater into the final configuration.

Table C-1. Ocean Transport of T1 Modules

Transport Vessel	Quantity On One Vessel		Transport Speed (knots)
	Number of Modules	Axial Length of Breakwater (ft)[a]	
LASH[b]	154 to 242	1,230 to 1,940	22
SEABEE	134	1,070	20
Barge[c]	108	860	3-1/2

[a]Configuration of Figure 11.

[b]Ranges of values correspond to the range of capacities of LASH ships.

[c]100 by 400 feet.

Time schedules for installing 1,070, 1,550, and 2,030 feet* of breakwater may be estimated from Figure C-4 as about 5-1/2, 7-1/2, and 9 days, respectively. These installation rates - 1.5 to 2.0 moored elements per day or 22 to 30 modules per day - are slower than the rates at which modules can be unloaded from transport vessels. Therefore, installation rate is the controlling factor, and temporary storage of a small number of unloaded but uninstalled modules is required if the transport vessel is to be unloaded as rapidly as possible.

*These actual lengths correspond to effective lengths of 640, 1,120, and 1,600 feet, respectively (see Appendix E).

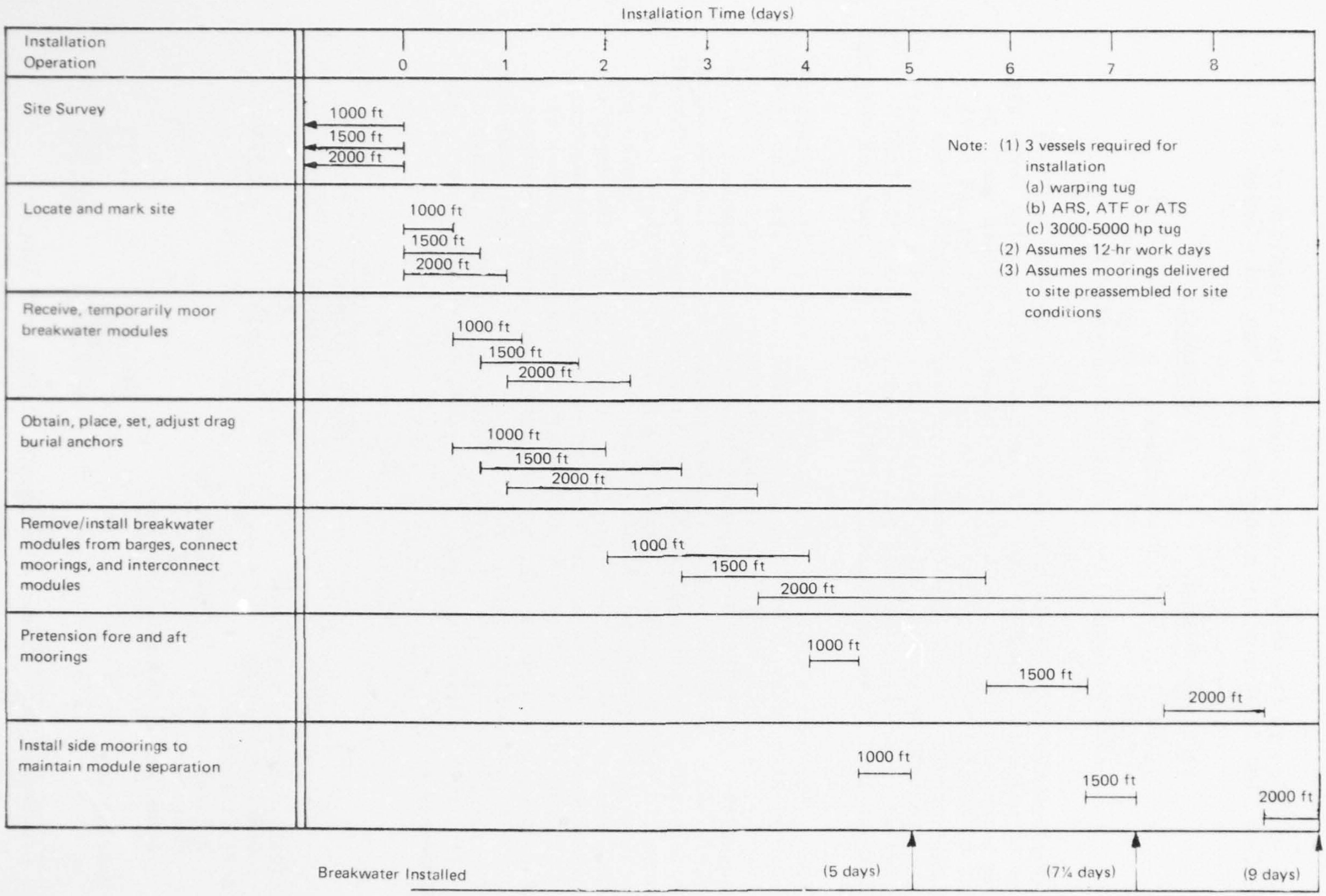


Figure C-4. Installation schedule for various lengths of tethered float breakwater (design T1).

In addition to the three workboats needed for installation (see Figure C-4), the following are needed for unloading and storing modules:

Transport Vessel	Workboats
LASH	3 tugs
SEABEE	4 tugs, 1 barge crane
100x400 barge	3 tugs, 1 barge crane

The barge-mounted crane would have to reach 50 or 60 feet and lift 85 tons to unstuff a SEABEE barge. To unload an ocean-going barge the maximum reach would be about 200 feet, although this figure could be reduced to about 120 feet if the crane barge is moved back and forth along the cargo barge – a time-consuming procedure. Possibilities for tugs are the LASH barge tug, which is compatible with the LASH gantry crane and which has been designed but not built, or, once the LASH cantilevered lift frame is acquired, a PHIBCB water-jet-propelled warping tug.

Cost. For cost estimating, the float is assumed to be a spherical, seamless, plastic float of the construction developed by the Lane Instrument Company, El Cajon, Calif., weighing 400 pounds and costing $450 in some quantity. One tether with special terminations is expected to cost $175 (Ref. 16). A tassled wiper attached to the float to inhibit marine growth (a patent has been applied for by the Naval Ocean Systems Center) is assumed to cost $25. The concrete ballast module for these floats weighs about 5,600 pounds per float and would cost $300 to $500/cu yd, the exact figure depending upon quantity. Depending upon the depth of water and the total length of the breakwater, moorings and connecting lines will add 10% to 15% to the above costs. Commercial fenders at $4,000 each would add about 20%; however, this cost would be reduced considerably by adapting surplus fuel bags at a cost of about $400 each.

The materials cost for a 7-second breakwater (similar to that of Figure 11), with moorings designed for less than a 100-foot depth, may be summarized as follows:

Item		Cost: Moored Element (420 Floats)	Cost: Front Foot*
Floats, wipers, tethers, and terminations		$273,000	$2,275
Ballast system			
Ballast mass	$281,000		
Fenders	12,800		
Lines and fittings	27,700		
		321,500	2,679
Mooring legs		42,700	356
		$637,200	$5,310

*For a breakwater with 15 moored elements, 1,800 feet long.

Design T2

Design T2 consists of reinforced-concrete triangular-frame ballast modules, 20 feet on a side and about 1.5 feet deep, designed to carry 5-foot spherical floats attached at the apexes and midway between apexes. The modules are assembled into a moored element (see Figure 14), an articulated framework nominally 100 feet wide. For a 7-second breakwater (37 rows), the length of the moored element would be 312 feet and the number of floats attached 346.

Transportation. For long-distance ocean transportation, the unassembled components (modules and connectors, trimming weights, and float-tether sets) can be carried on large ocean-going barges (Ref. 16) and on barge-ships (LASH and SEABEE). The material for 10 moored elements, 100 by 312 feet, would be an average load for a 100 by 400-foot barge. Material for 8 to 15 moored elements could be carried aboard a LASH vessel, depending upon the particular vessel, and material for 31 could be carried on a SEABEE. As noted previously, however, the availability of a SEABEE for COTS is unlikely.

The shipping of components unassembled has inherent disadvantages which may be undesirable in Navy applications. With reference to barge-ship transportation, a calm-water storage area at the destination is required for the full complement of the ship's lighters; otherwise the layover time for the mother ship would be excessive. If the assembly site and the installation site are not the same, the moored elements must be towed from one site to the other. For any mode of ocean transportation, the shipping of components unassembled involves considerable time at the destination for assembly prior to installation.

Assembled, one moored element can be shipped on a 100 by 400-foot barge, although this is not economical use of the barge's capacity. The barge should be a submergible type. Details of the unloading operation have to be completed.

To summarize, Table C-2 shows the number of moored elements which could be carried aboard one vessel. The quantity of breakwater material is also expressed in terms of the axial length of a 7-second breakwater.

Installation. Prior to installation, unassembled components on a seagoing barge or in LASH or SEABEE barges would be delivered to a drydock site, a harbor, or other quiet water where there are facilities for unloading the barges and space for storing the bargeships' lighters and unloaded breakwater components. One or more small cranes would be required, as well as means for moving components from a storage area to another crane used for assembly.

A proposed method is to assemble a moored element on a barge, 110 by 320 feet, in quiet water or in a drydock. The barge must be a submergible type. Seven days is estimated as the time needed for assembly. The moored element would then be towed to the breakwater site, launched from the barge by submerging it, and then towed with ballast submerged to the desired location for installation. Because the moorings are similar, the installation procedure would be approximately as described for the T1 design. More details are presented in References 16 and 24.

Table C-2. Ocean Transport of T2 Modules

Transport Vessel	Quantity on One Vessel: Number of 100-Foot Moored Elements	Quantity on One Vessel: Axial Length of Breakwater (ft)[a]	Transport Speed (knots)
Modules Not Assembled Into Moored Elements			
SEABEE	31	3,100	20
LASH[b]	8-15	800-1,500	22
Barge[c]	10	1,000	3-1/2
Modules Assembled Into Moored Elements			
Barge[c]	1	100	3-1/2

[a]Configuration of Figures 15 and 16.

[b]Ranges of values correspond to the range of capacities of LASH ships.

[c]100 by 400 feet.

Vessels for installation are as follows: one ocean-going 110 by 320-foot submergible barge for each moored element being assembled simultaneously, with tug; four tugs (3,000 to 5,000 hp) for unloading, moving, and positioning a moored element during installation; and one warping tug, ARS, or ATF for marking and placing anchors.

Installation time is estimated as follows: 1 day for pre- and post-assembly operations for each moored element; 7 days to assemble one moored element; time to tow one barge carrying a moored element from assembly site to installation site; and 1 day to unload, position, and install one moored element. Thus, the times to install 900, 1,400, and 1,900 feet of breakwater (effective lengths of 500, 1,000, and 1,500 feet) after delivery of components overseas, assuming that moored elements are not assembled simultaneously and neglecting time for transit from assembly site to breakwater site, are 73, 113, and 153 days, respectively.

Cost. Data for floats and tethers are as assumed previously for design T1. The ballast cost is estimated as $160 per float. The flexible intermodule connectors are a development item and are assumed to cost

$1,500 each. Lines and fittings for connecting moored elements will add 5% to 15% to the foregoing costs, and moorings will add 5% to 10%, depending upon the water depth and the length of the breakwater.

The materials cost for a 7-second breakwater (similar to that of Figure 15), with moorings designed for less than 100-foot depths, may be summarized as follows:

Item		Cost: Moored Element (346 Floats)	Cost: Front Foot
Floats, wipers, tethers, and terminations		$224,900	$2,250
Ballast system			
Ballast mass	$ 55,500		
Connectors	121,500		
Lines and fittings	65,000		
		242,000	2,420
Mooring legs		40,000	400
		$507,000	$5,070

Design T3

Design T3 consists of 128 cylindrical floats approximately 2 feet in diameter and 4 feet high assembled from automobile tire casings and attached to a steel-frame ballast module, 30 feet by 60 feet in plan (see Figure 17). The weight of the ballast module and the floats is 90 tons. Logistics-related properties such as cost or installation time per increment of axial length, which are functions of the beam dimension of the breakwater, are omitted from the following discussion since performance data covering the expected ranges of water depth, submergence, and float properties are a necessary input.

Transportation. For long-distance ocean transportation, the modules can be carried on ocean-going barges or on bargeships in approximately the numbers previously noted for design T1. The way in which the attached floats are carried on the ballast module aboardship has not yet been worked out. If the float-tether assemblies can be transported on the ballast modules in a way which permits stacking the modules like T1 modules, then the data in Table C-1 on numbers of modules carried on various vessels are applicable to T3 modules. However, the data in Table C-1 on length of breakwater do not apply to the T3 design.

Installation. The installation procedure outlined below is one of several possibilities suitable for other designs also, including nonrecoverable types of ballast. For this procedure, it is assumed that a module, upon placement in the water, is taken directly to the breakwater.

As outlined, the procedure applies when modules are delivered on a LASH vessel or on a seagoing barge. If the modules are transported on a SEABEE, preliminary steps must be taken to (1) offload the SEABEE barges,

(2) extract breakwater modules and temporarily store them, and (3) refloat and move them to the floating crane. As noted previously, however, for COTS breakwaters, a SEABEE is not likely to be available.

The following procedure is illustrated in Figure C-5:

1. The modules are placed in the water one at a time by either the LASH gantry crane or the floating crane used to unload the cargo barges. The required static lift is about 90 tons. The required reach for the crane is the same as for the T1 modules.

2. Workboats alongside the crane attach temporary flotation utilizing pelican hooks for attachments.

3. The crane releases the module.

4. The workboats move the module a short distance to an LCM-8, which takes over the module.

5. The LCM-8 transports the module to the breakwater site.

6. The LCM-8 and one workboat position the module.

7. The LCM-8 releases the pelican hooks, allowing the module to sink. Float entanglement is prevented by having the floats previously secured to the ballast frame.

8. The LCM-8 pulls rods holding the floats to the ballast frame, and the floats rise to the operating position.

9. The LCM-8 returns to the crane and delivers the auxiliary flotation system to the workboats at the crane's working site.

Vessels required, in addition to the cranes noted above, are two LCM-8's for transporting and installing modules and three 35-foot workboats for placing flotation and assisting in positioning modules. In addition, for SEABEE transportation, two additional small tugs or other boats are required to take SEABEE barges to and from storage if this is done concurrently with installation of the breakwater.

The rate of installation, in terms of the axial length of breakwater installed in a day, depends upon the beam dimension of the breakwater; that is, the number of rows of floats.

Cost. Proposals to supply floats for the ocean experiment have ranged between \$50 and \$500 per float; here, \$100 is assumed. Estimated cost for one tether with terminations is \$25. The cost of the steel ballast can vary from \$0.20 to \$0.50/lb, depending upon the local availability of material. Here, \$0.25 is assumed. Thus, a rough estimate for the fabricated cost is as follows:

Item	Cost Per Float
Floats, tethers, and terminations	\$125
Ballast system	225
TOTAL	\$350

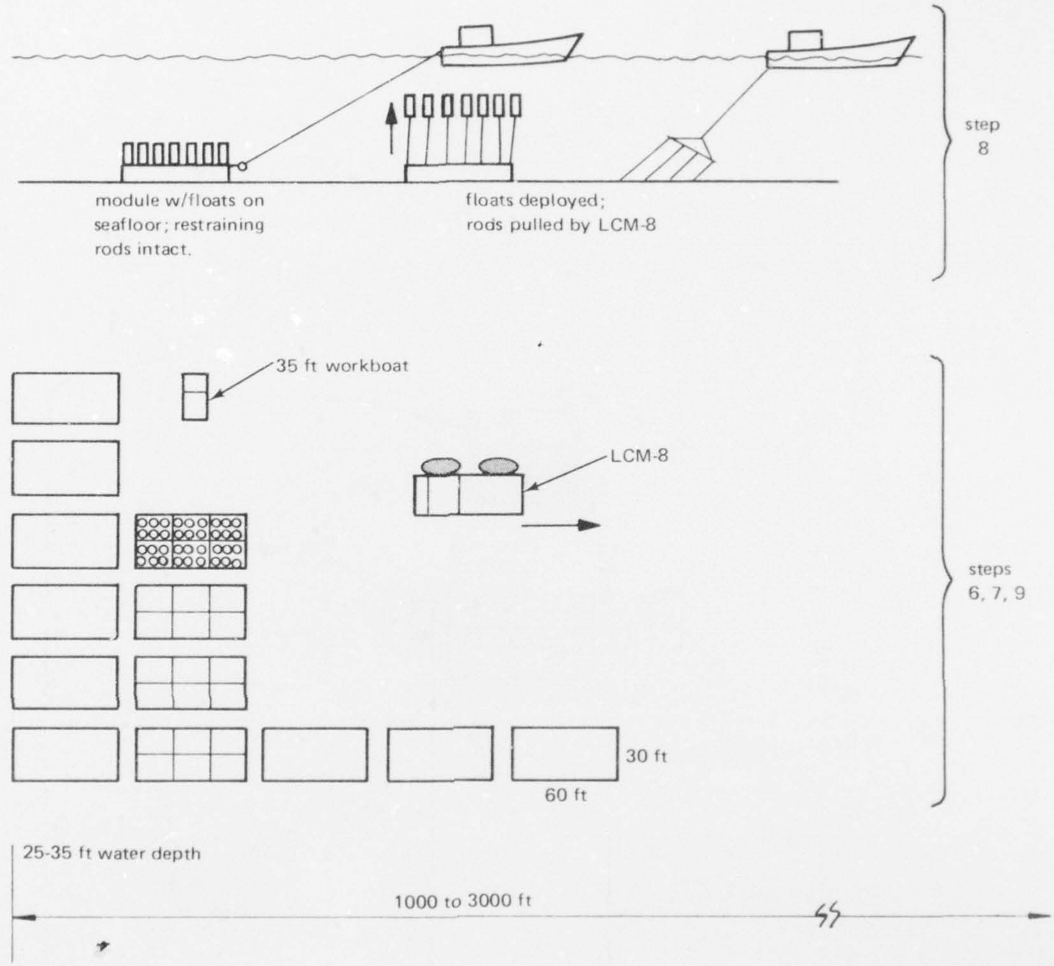


Figure C-5. Tethered float breakwater: installation of bottom-resting system (design T3).

AD-A062 432 CIVIL ENGINEERING LAB (NAVY) PORT HUENEME CALIF F/G 13/2

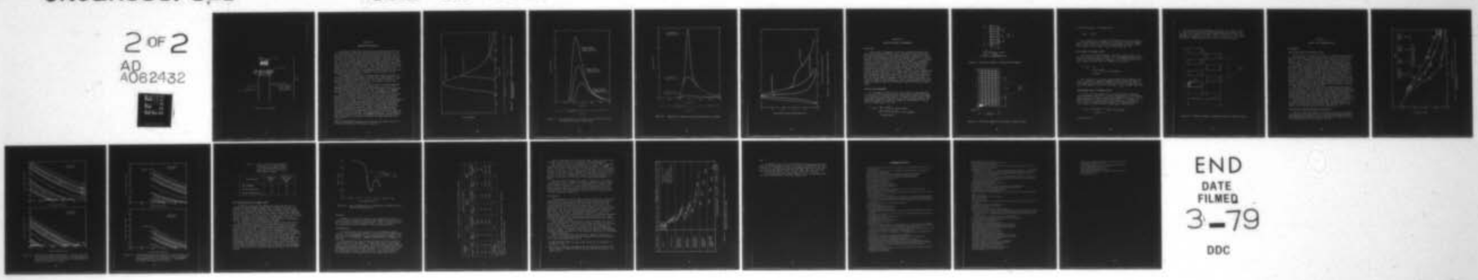
AN ASSESSMENT OF TRANSPORTABLE BREAKWATERS WITH REFERENCE TO TH--ETC(U)

SEP 78 D B JONES

UNCLASSIFIED CEL-TN-1529 NL

2 OF 2

AD A062432

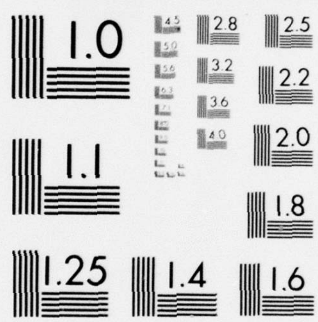


END

DATE FILMED

3-79

DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

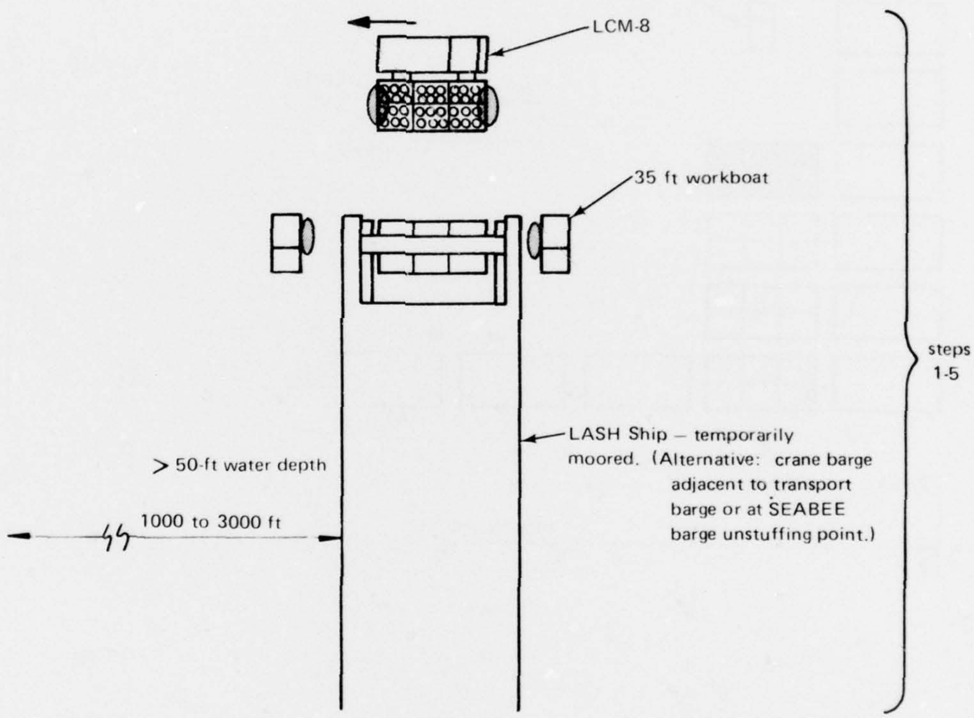


Figure C-5. Continued

Appendix D

REFERENCE WAVE SPECTRA

The dominant heights and periods of waves being generated by the wind depend upon the distance upwind from the point in question to the far end of the area over which the wind has been blowing (the fetch of the wind), the width of the fetch area, the speed of the wind, and the length of time in which the wind has been blowing. The wave spectrum for the point in question grows as time passes, as illustrated in Figure D-1. This simplified example pertains to steady wind and to unlimited length and unrestricted width of the fetch. When growth has practically ceased, the sea is "fully developed." Both the significant wave height, which varies as the square root of the area under the graph of the spectrum, and the wave period corresponding to the peak of the spectrum, which identifies the spectral components carrying the most energy, increase as the sea develops.

The dependence of the fully developed spectrum upon the speed of the wind is shown by the examples of Figure D-2. These graphs are plots of Pierson-Moskowitz spectra (Ref. 26). This family of spectra is in wide use as the descriptor for the case of unlimited, unrestricted fetches with moderate to strong winds.*

Under fetch-limited conditions, spectra that are more peaked than the Pierson-Moskowitz spectrum are observed (Ref. 27 and 28). The JONSWAP family of spectra was derived from measurements obtained during the Joint North Sea Wave Project (Ref. 28). An example of a JONSWAP spectrum is compared in Figure D-3 to a Pierson-Moskowitz spectrum.

The third spectrum shown in Figure D-3 is an artificial case which was devised to represent, by means of a spectrum readily expressible mathematically, certain bimodal sea-plus-swell spectra which may be observed in nature (Ref. 6). This example consists of a Pierson-Moskowitz spectrum for a 9.3-knot wind (peak period at 3.5 seconds) superimposed on a reduced Pierson-Moskowitz spectrum for an 18.6-knot wind (peak period at 7 seconds) in which all spectral energy values (ordinates) have been multiplied by one-ninth. While the swell component may be less broad-banded than in this formulation, this modified spectrum illustrates the increased breadth of spectrum that can result from such superposition of wave systems. The modified spectrum is the broadest of the three in Figure D-3, while the JONSWAP spectrum is the most peaked. This is brought out by plotting the spectra in normalized form, as in Figure D-4.

---

*The Pierson-Moskowitz formulation was derived from storms with 20- to 40-knot wind speeds at 19.5 meters' elevation.

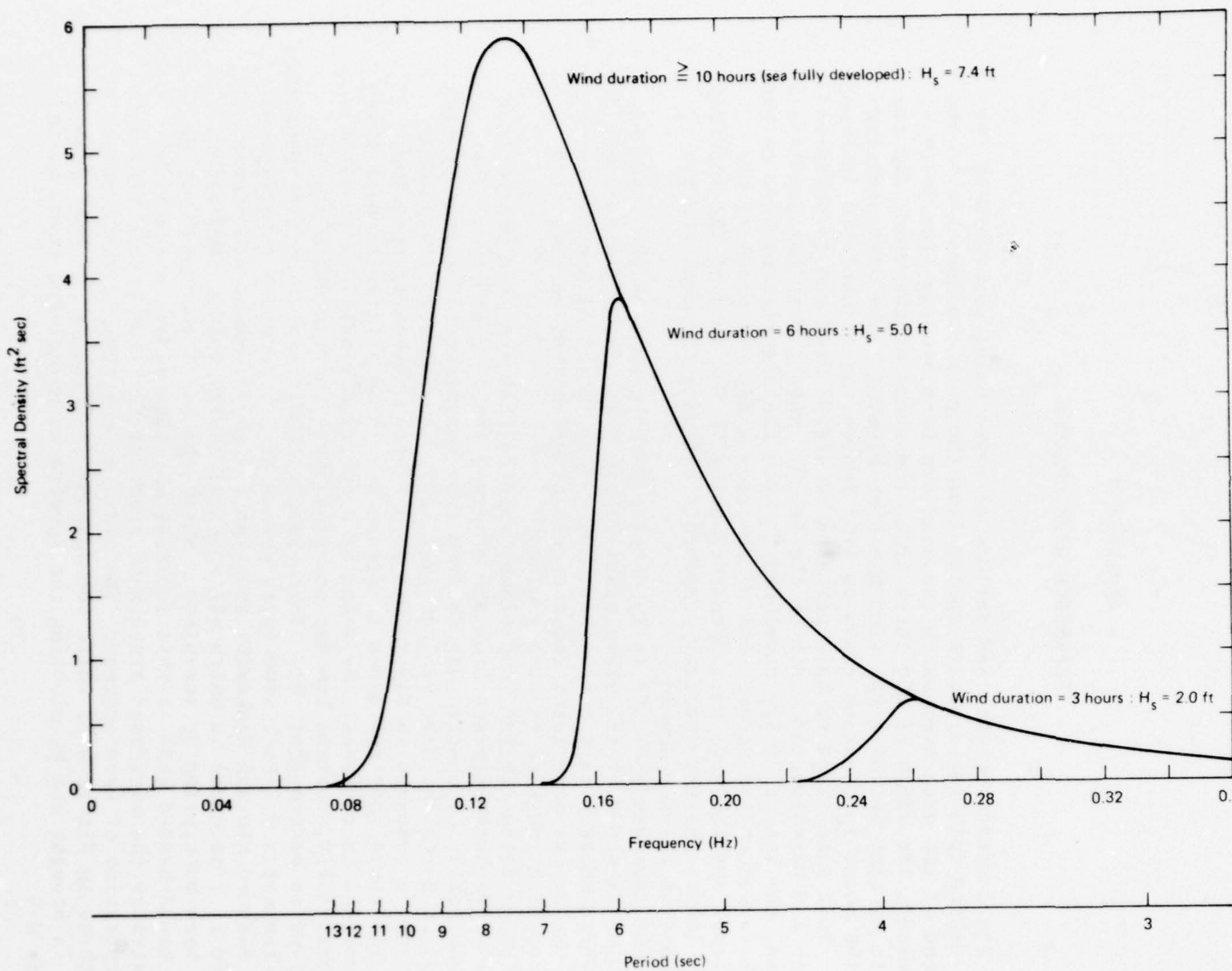


Figure D-1. Wave spectrum growth: Illustrative example for 20-knot wind (based on Reference 29).

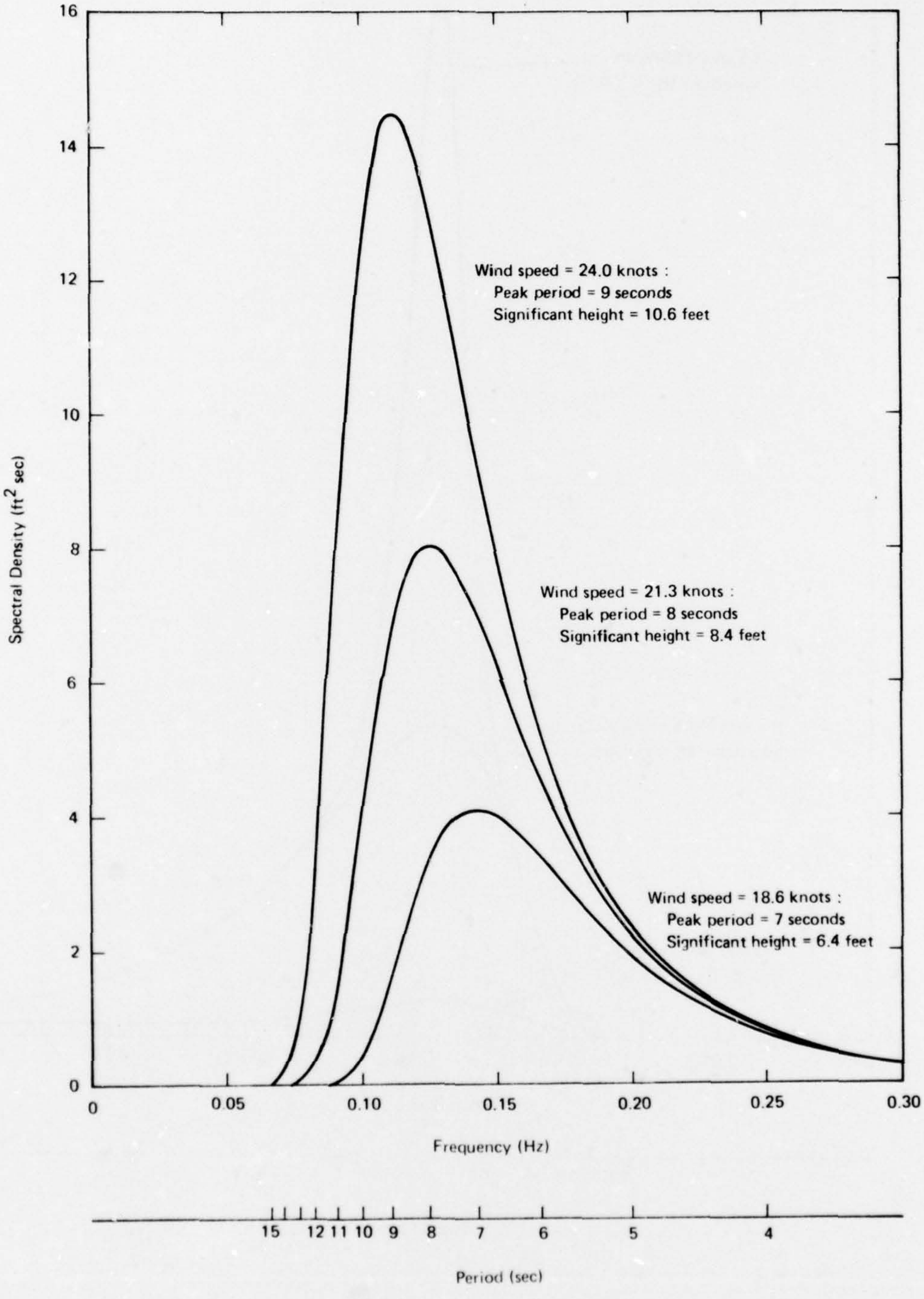


Figure D-2. Pierson-Moskowitz wave spectra for fully developed seas: illustration of effect of wind speed.

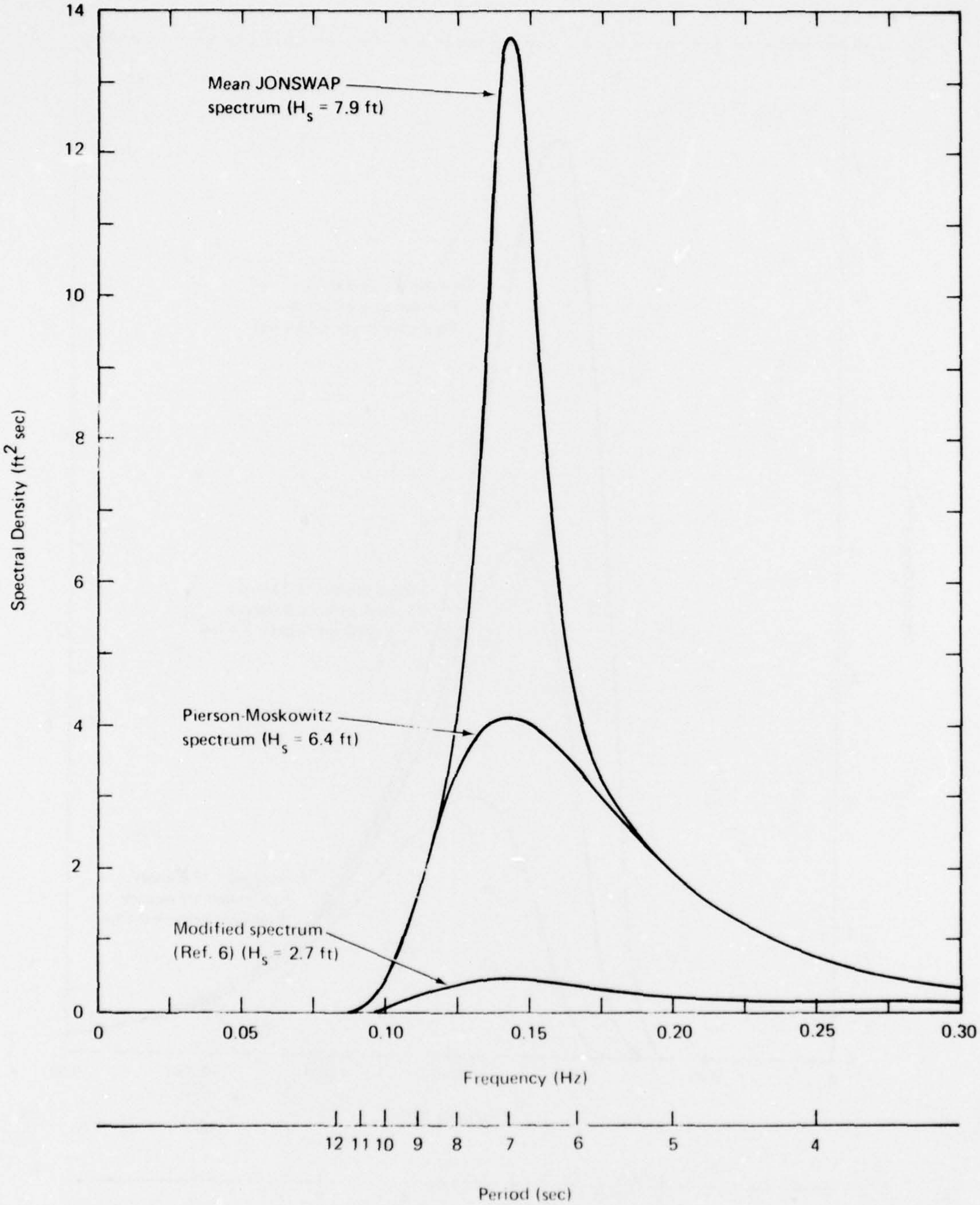


Figure D-3. Comparison of three wave spectra with peaks at 7 seconds.

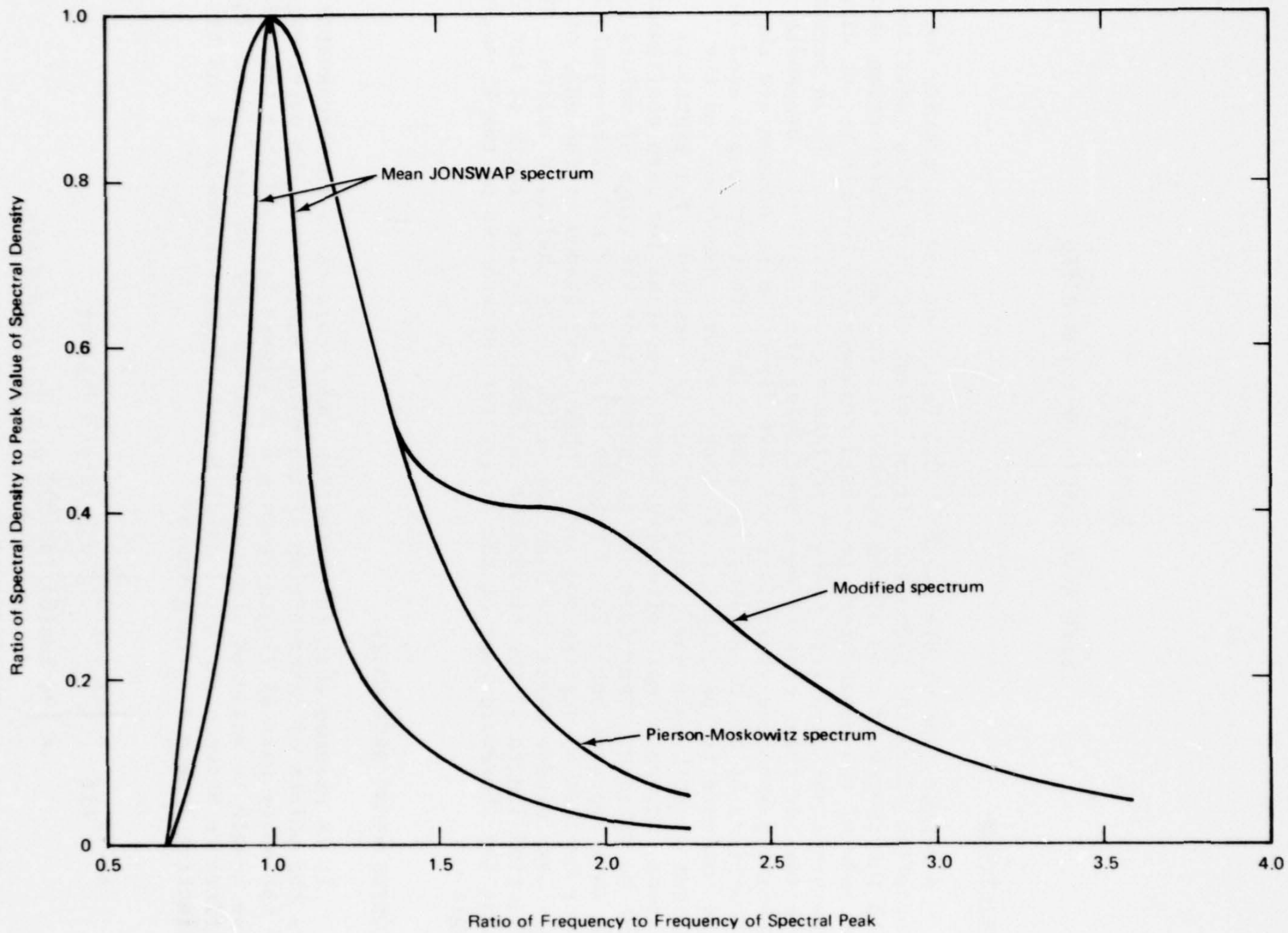


Figure D-4. Comparison of normalized wave spectra.

Appendix E

EFFECTIVE LENGTH OF BREAKWATERS

DEFINITION

A ribbon type of breakwater 1,000 feet long may not provide full protection along the 1,000-foot front, along the line which coincides with the shoreward side of the breakwater, because of diffraction about the ends of the breakwater, increased transmission through it, or direct exposure associated with oblique incidence of the waves. It is necessary to allow for these effects when specifying the length of a breakwater, especially when the variability of wave direction is unknown and the orientation of the breakwater is fixed. The effective length used in this analysis is the actual axial length minus a deduction for the regions at both ends where wave shelter is lessened. For practical reasons, an approximate effective length, constant for each configuration, must be defined. Therefore, it is assumed that the range of values of the wave approach angle 2θ in Figures E-1, E-2, and E-3 often equals but never exceeds 45 degrees and that a sharp wave shadow at the edge of this wave window marks the boundary of the fully sheltered region. The effective length of the breakwater is taken to be the length of the line along the shoreward edge of the breakwater intercepted by the 45-degree angle.

SLOPING FLOAT BREAKWATER

It is assumed that the effective inner corners of the breakwater are the points of intersection of the water surface and the outer edges of the outer pair of floats (points E in Figure E-1) and that the effective length is measured along the line of the toes of the floats. The difference between the total axial length of the breakwater A and the effective length A_{eff} is given by

$$\begin{aligned} A - A_{eff} &= \left[2x \tan(\theta)\right]_{\theta = 22\text{-}1/2 \text{ degrees}} \\ &= \left[2d \tan(\theta)/\tan(\alpha)\right]_{\theta = 22\text{-}1/2 \text{ degrees}} \\ &= 0.828\ d/\tan(\alpha) \end{aligned}$$

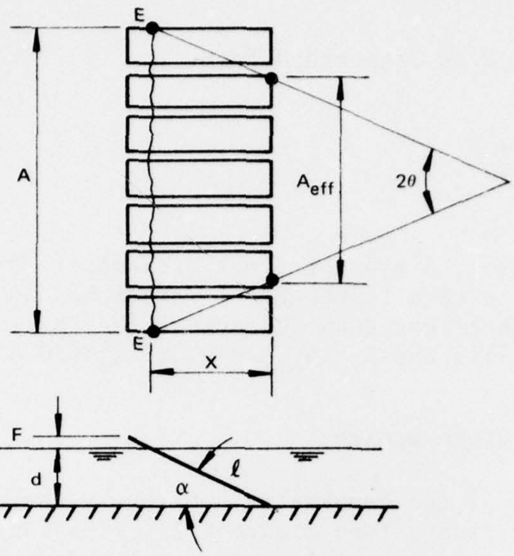


Figure E-1. Effective length of sloping float breakwater.

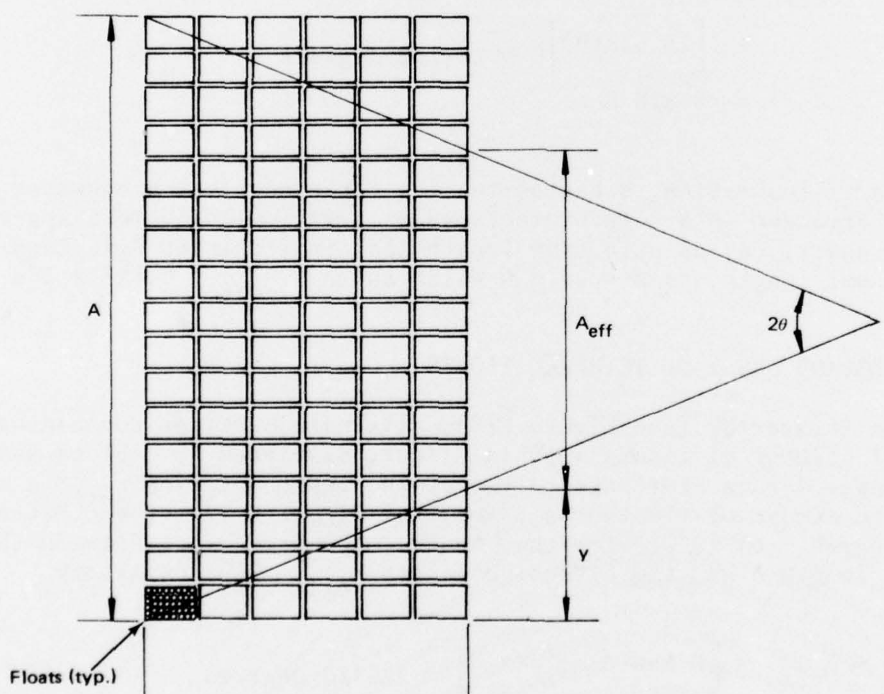


Figure E-2. Effective length of solid array of tethered floats.

in which the angle α is determined from

$$\sin(\alpha) = \frac{d + F}{\ell}$$

For illustration, a sloping float breakwater 90 feet long placed in water 30 feet deep with a freeboard of 7 feet has an effective length that is about 50 feet less than the actual length, as $\sin(\alpha) = 37/90 = 0.411$, $\tan(\alpha) = 0.451$, and $A - A_{eff} = 0.828 \times 30/0.451 = 50$.

SOLID ARRAY OF TETHERED FLOATS

Near the ends of the breakwater, obliquely incident waves do not pass all n rows of floats (see Figure E-2). The maximum wave protection exists only over the length of line A_{eff}. The difference between the axial length A and the effective length A_{eff} is given by

$$\begin{aligned} A - A_{eff} &= 2y \\ &= \Big[2B \tan(\theta)\Big]_{\theta\, =\, 22\text{-}1/2 \text{ degrees}} \\ &= 0.828\ B \end{aligned}$$

For illustration, a bottom-resting tethered float breakwater with floats arranged in a compact rectangular array, with 50 rows spaced 4 feet apart, has an effective length that is about 160 feet less than the actual length, as $B = 49 \times 4 = 196$ and $A - A_{eff} = 0.828 \times 196 = 162$.

CHECKERBOARD ARRAY OF TETHERED FLOATS

In this array (see Figure E-3), alternate sections containing several columns of floats are, in effect, displaced as a block seaward. Waves pass n rows of floats only over the length of line A_{eff}; n is the required number of floats, as taken from Figure C-1. If the ratio $(2a + d)/(b + c)$ is greater than $\tan(\theta)$, the difference between the actual length A and the effective length A_{eff} is approximately

$$\begin{aligned} A - A_{eff} &= \Big[B \tan(\theta) + a + d\Big]_{\theta = 22\text{-}1/2 \text{ degrees}} \\ &= 0.414B + a + d \end{aligned}$$

in which $B = 2b + c$.

For illustration, the breakwater in Figure 11 ($a = 105$, $b = 325$, $c = 100$, and $d = 15$ feet) has an effective length about 430 feet less than the actual length, since $(650 + 100)0.414 + 105 + 15 = 430$. The breakwater in Figure 15 ($a = 100$, $b = 312$, $c = 100$, and $d = 0$ feet) has an effective length about 400 feet less than the actual length.

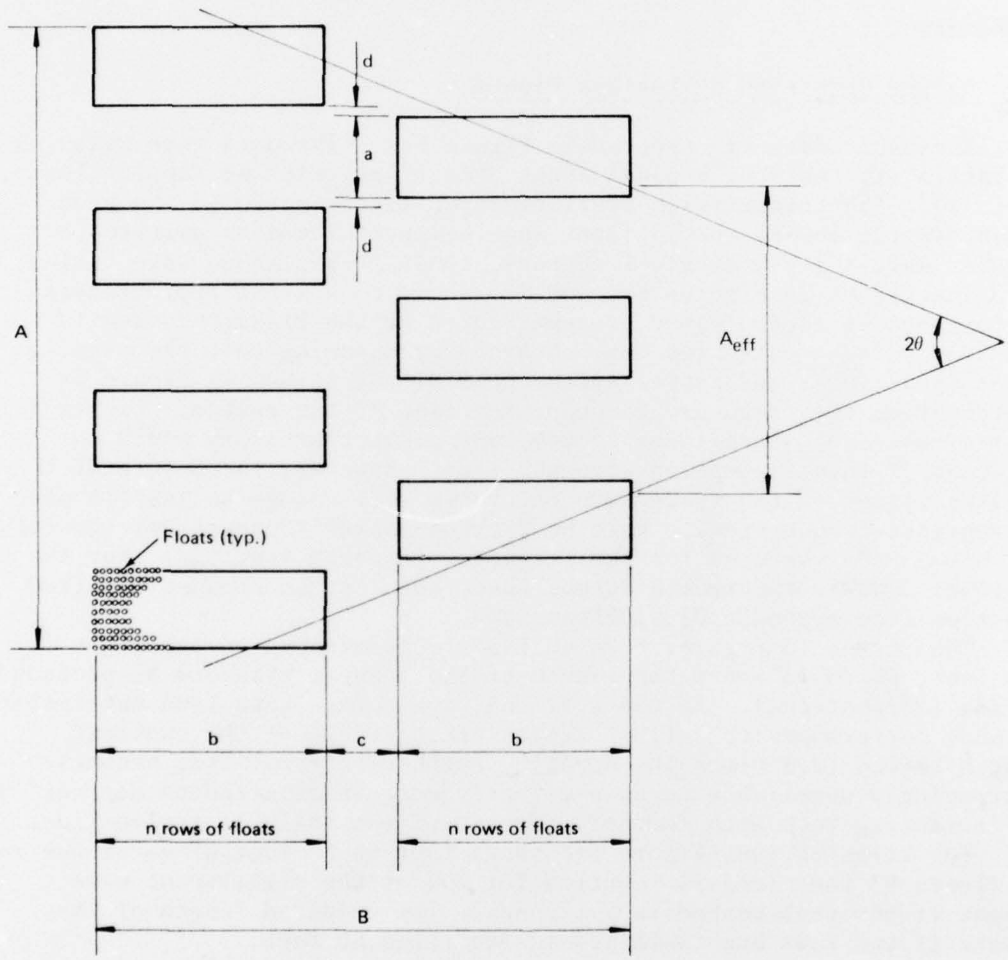


Figure E-3. Effective length of checkerboard array of tethered floats.

Appendix F

SLOPING FLOAT BREAKWATER DATA

PERFORMANCE

Wave Height Reduction By Legless Floats

The basic data are plotted in Figure F-1. The data were measured in laboratory tests of a panel about 3 feet long with no gap (no legs) (Ref. 3). The transmission coefficient C_T is the ratio of the wave height in the lee to the incident wave height. The data pertain to regular waves; i.e., single-frequency, constant-amplitude wave trains.

The graphs in Figures F-2 and F-3 show, to a first approximation, performance in random waves as represented by the Pierson-Moskowitz spectrum. These estimates were obtained by assuming that the sloping float is a linear mechanical system, one of the curves in Figure F-1 representing the frequency-response function of the system. Figure F-1 is indicative of a nonlinear system, and greater accuracy would be obtained if this assumption were not made. However, the nature of the nonlinearities of the system are not known well enough to justify more appropriate computations. For the Pierson-Moskowitz spectrum, the curve for $H/L = 0.04$ was used for the frequency-response function. For the narrower JONSWAP spectrum 0.06 was used, and for the broader modified spectrum (see Appendix D) 0.02 was used.

The curves in Figures F-2 and F-3 are terminated on the right at 180 feet, which is about the length of the longest standard NL pontoon string (30 pontoons). At the left end, the curves have been extrapolated to what corresponds to a float length of about 90% of the shortest length tested (2.9 times the depth). Further extrapolation becomes increasingly unreliable because effectiveness is expected to decrease at an increasing rate with further increase of the angle of inclination.

For illustration, Figure F-2 shows that in 30 feet of water one row of floats 93 feet long is required for 50% of the significant wave height if the peak period is 7 seconds. The required length of the floats if two rows are installed is less than 80 feet.

Effect of Wave Spectrum Breadth on Performance

Table F-1 shows the results of a calculation check to investigate performance for wave spectra that are broader and narrower than the Pierson-Moskowitz spectrum. In all cases, the float length is 93 feet, water depth 30 feet, and wave period 7 seconds.

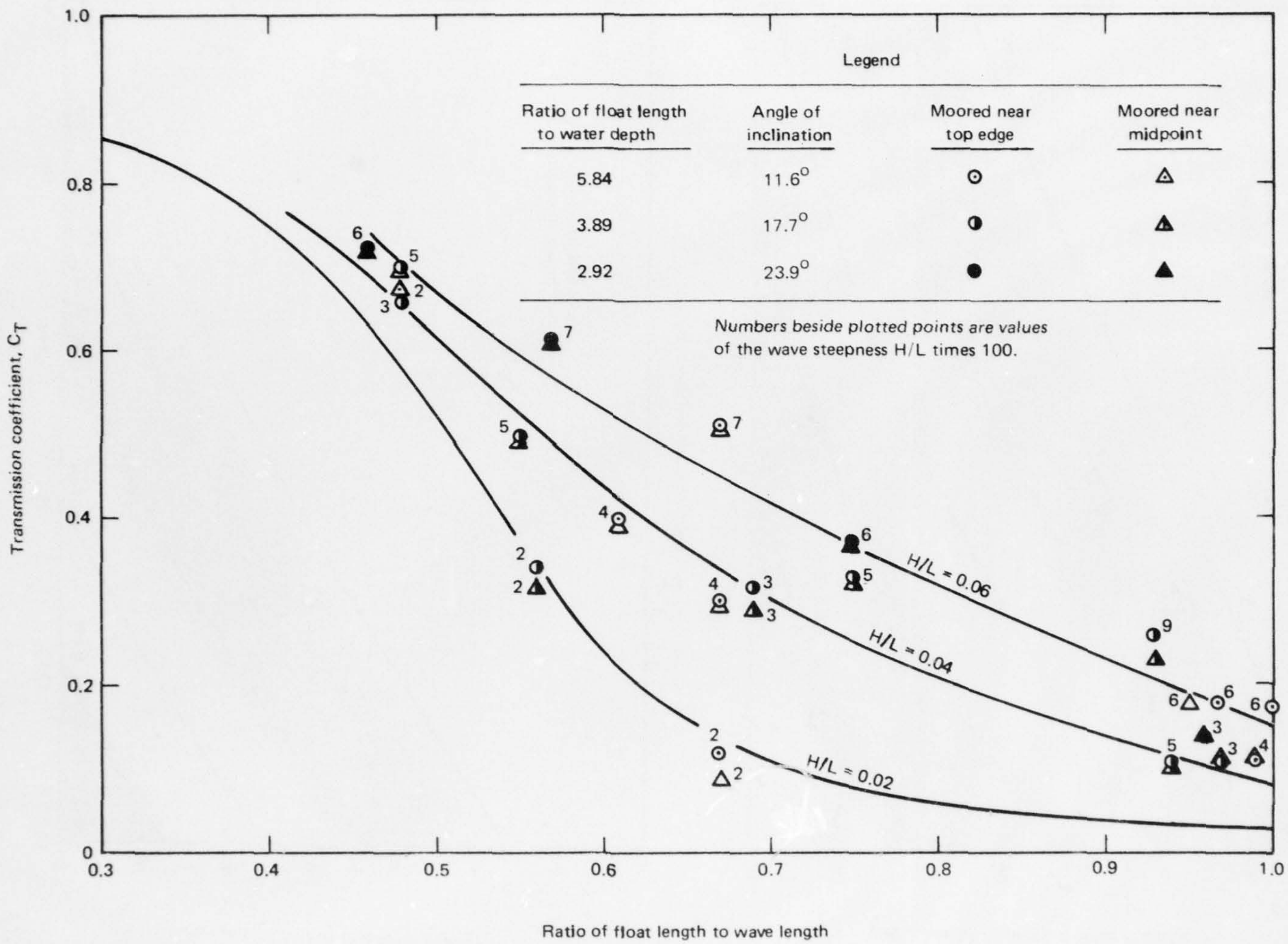


Figure F-1. Wave transmission for a sloping float in regular waves (laboratory data).

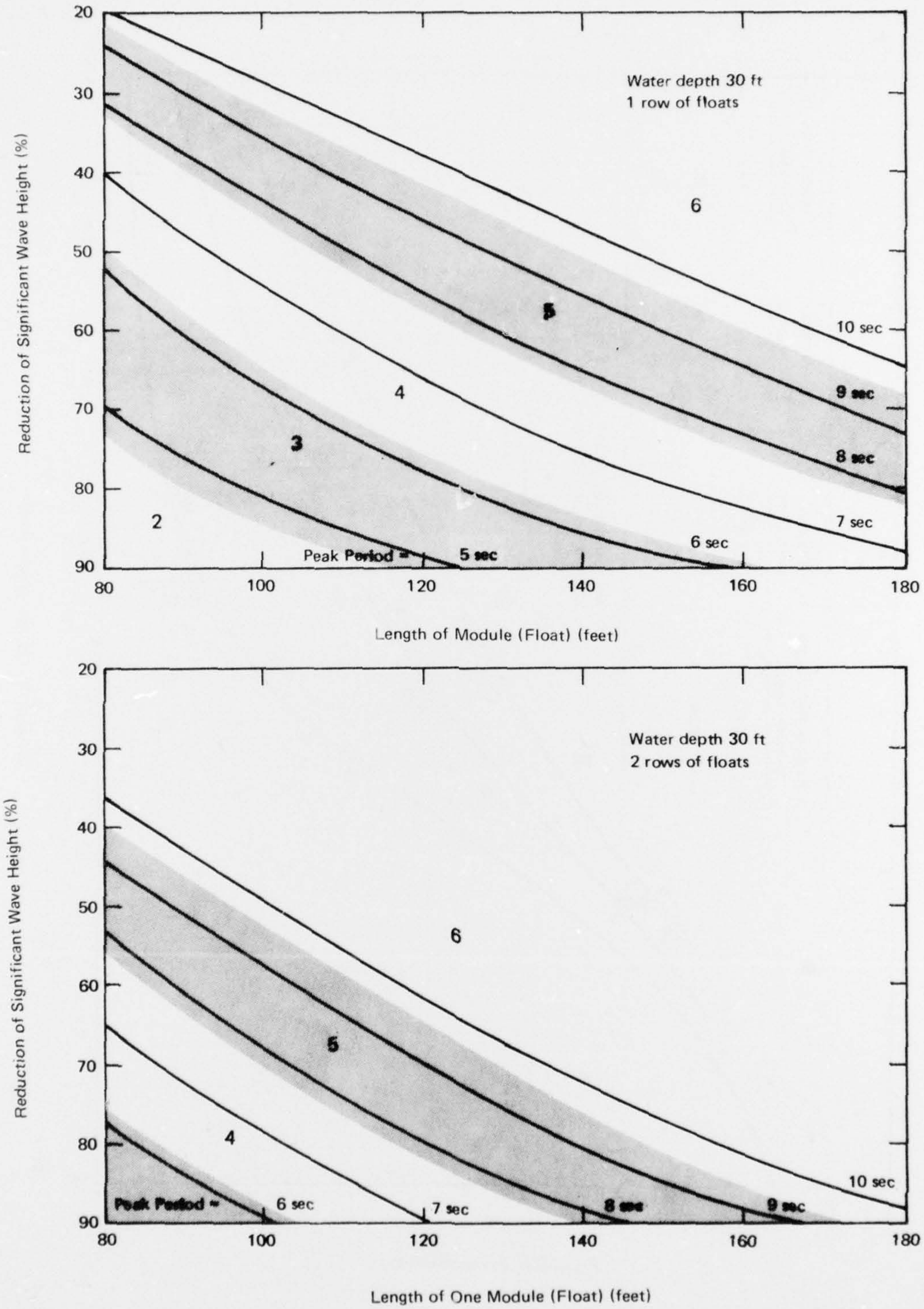
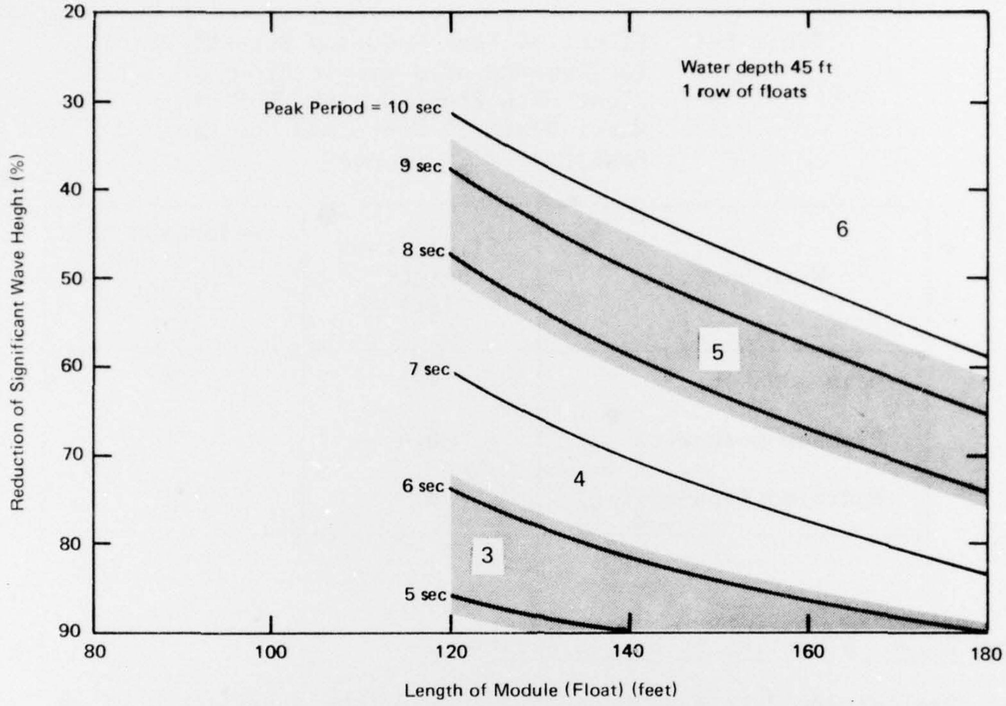


Figure F-2. Sloping float breakwater performance in 30-foot deep water and Pierson-Moskowitz wave spectrum. First approximation from laboratory data for simple floats. (Bold numbers and shaded areas indicate sea states.)



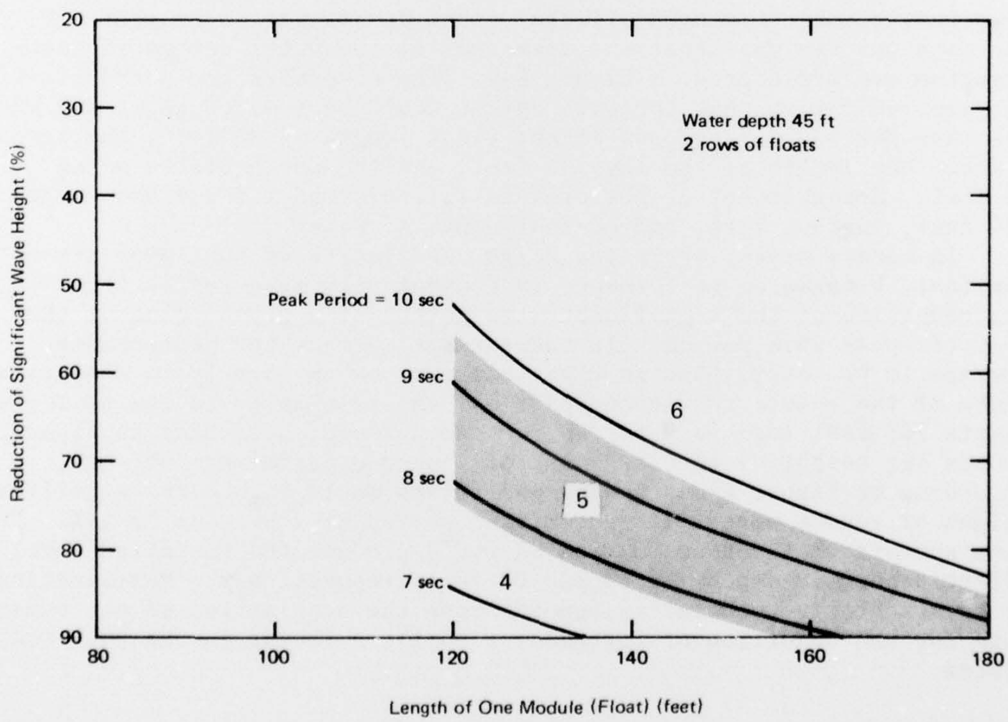


Figure F-3. Sloping float breakwater performance in 45-foot deep water and Pierson-Moskowitz wave spectrum. First approximation from laboratory data for simple floats. (Bold numbers and shaded areas indicate sea states.)

Table F-1. Effect of Wave Spectrum Breadth on Performance of a Simple Sloping Float With Float Length 93 Feet, Water Depth 30 Feet, and Spectral Peak Period 7 Seconds

Wave Spectrum	Significant Height (ft)	Reduction of Significant Height (%)
Mean JONSWAP	7.9	44
Pierson-Moskowitz	6.4	50
Modified (Appendix D)	2.7	66

Wave Height Reduction by Legged Floats

Preliminary data have been obtained in laboratory tests of an unmoored, pivoting (hinged), legged float in regular waves (Ref. 25). The data for the case that the lower 30% of the water column is unobstructed are reproduced in Figure F-4. These results are not definitive but are indicative that the wave height would be reduced about 50% when the wave period is 7 seconds if the float length is 90 feet, the freeboard 6 feet, the length of the legs 30 feet, and the depth of the water 40 feet. Somewhat better performance is indicated for a float length of 120 feet, 40-foot legs, and 60-foot depth of water.

In random waves, where the height and length of the waves are not constant, breakwater performance is conveniently measured in terms of the reduction of the significant wave height at a given value of the spectral peak wave period. In these terms, breakwater performance appears to be better than in regular waves, owing largely to nonequivalence of the reference wave properties. As an example, a row of legless floats 107 feet long in water 30 feet deep would, according to Figure F-1, reduce the height of regular waves of 7-second period by 50%; but, according to Figure F-2, the legless floats would reduce the significant height of random waves with a dominant period of 7 seconds by 59%. It thus appears that designs S2 and S3 would produce the specified level of effectiveness in depths of 40 and 60 feet, respectively. Verification of this tentative conclusion depends upon the acquisition of performance data for the condition of restraint actually existing in the full-scale system.

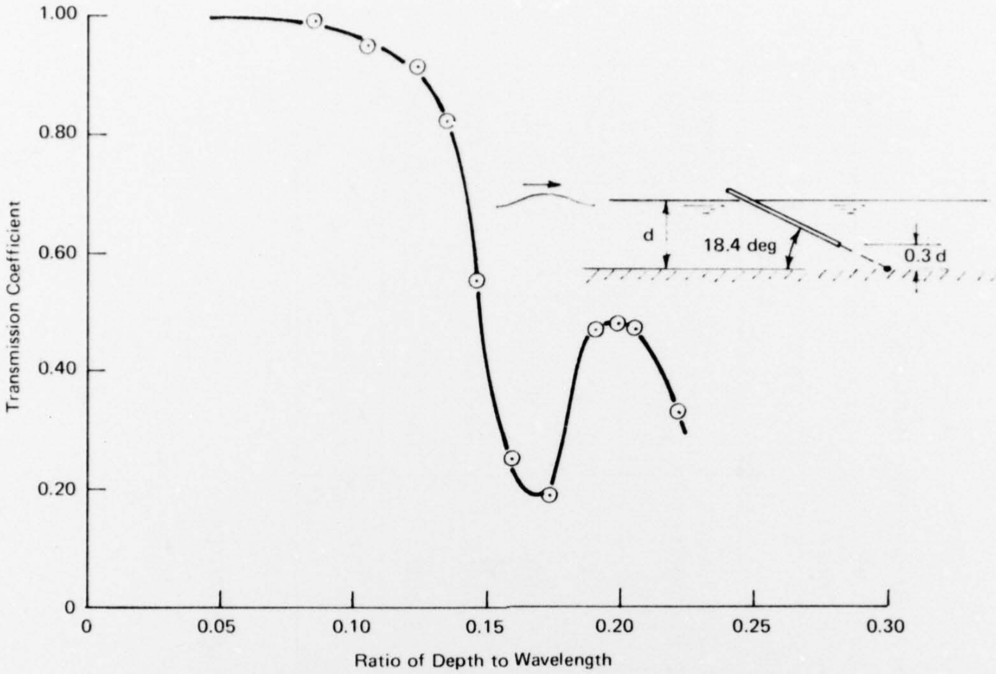


Figure F-4. Wave transmission for a hinged plate with 30% open area based on laboratory data.

LOGISTICS

Estimates are easiest for legless floats adapted from 3x15 NL pontoon sections (design S1, Figures 21-23) because this design involves the least amount of engineering development. However, rough estimates for designs S2 and S3 are included in the following discussion.

Transportation

For long-distance ocean transportation, the breakwater modules could be carried on ocean-going barges, in vessels with well decks (LSD, LPD, LHA, or the TRIMARINER), or in bargeships (LASH and SEABEE). The capacities of a large barge, a SEABEE, and LASH ships are summarized in Table F-2.

An average load for a 100 by 400-foot barge is between 2,000 and 3,000 lineal feet of breakwater. To unload the barge, a large ringer crane could be required. The static lift would vary from 30 to 130 tons, depending upon the particular module design. For a barge-mounted crane the maximum radius would be about 200 feet if its location relative to the cargo barge is fixed, or about 120 feet if the slow procedure of moving back and forth along the side of the cargo barge is used.

Table F-2. Ocean Transport of Sloping Float Breakwater Modules

Breakwater Module		Quantity on One Vessel					
		Barge[a]		SEABEE		LASH[b]	
Design	Width (ft)	Number of Modules	Axial Length of Breakwater (ft)	Number of Modules	Axial Length of Breakwater (ft)	Number of Modules	Axial Length of Breakwater (ft)
S1	21	112	2,800	0	0	30	750
S2a	28	84	2,800	154	5,100	30	1,000
S2b	28	63	2,100	115	3,800	70-110[c]	2,300-3,600
S3	28	63	2,100	115	3,800	70-110[c]	2,300-3,600
Transport Speed (knot)		3-1/2		20		22	

[a] 100 by 400 feet.

[b] Range of values corresponds to the range of capacities of LASH ships.

[c] Includes 21 modules on hatch covers.

Faster transportation is provided by ships. Ships with well decks, although capable,* would not be available for COTS breakwaters.

The carrying capacity of bargeships varies a great deal, depending upon both the type of ship and the design of the module. A SEABEE cannot readily handle 3x15 sections or other floats 21 feet wide because they are too narrow. If the floats are 28 feet wide, 115 to 154 modules (3,800 to 5,100 lineal feet of breakwater) apparently could be carried in place of the ship's barges, making this ship the most capable carrier for the sloping float breakwaters. However, as noted elsewhere, a SEABEE is not likely to be available for transporting breakwaters for COTS.

Special design of hardware that makes it feasible to stack modules of design S2b or S3 in a LASH in the spaces normally occupied by the ship's lighters would result in a carrying capacity of 2,300 to 3,600 lineal feet of breakwater of either of these two designs, the exact number depending upon the particular ship. Otherwise, only the space atop the hatch covers could be used, and only 700 to 1,000 lineal feet could be carried (see Table F-2).

Installation

Floating modules of the S1 design would be connected to each other, temporarily held in position by tugs, and connected to the moorings, which would have been preset so that the lines are slack after the connections have been made (refer to Figure 23). The valves in the manifold headers on the floats would then be opened in quick succession, beginning at one end. The valves would be reached from a warping tug or small boat. The venting of the pontoons permits water to enter the ports in the lower sides. The shoreward ends sink at a slow rate, depending upon the size selected for the ports. In an optional procedure permitting more control, a vacuum pump is attached to the vent. When flooding is complete, the shoreward moorings are adjusted, if necessary, and side moorings attached.

Time schedules for installing 600, 1,200, and 1,800 lineal feet** are shown in Figure F-5. The installation times are about 3, 4-1/2, and 6 days. These installation rates - about 8, 10, and 12 modules per day - are slower than the rates at which modules can be unloaded from transport vessels. Therefore, installation rate controls, and temporary storage of modules is required if the transport vessels are to be unloaded as rapidly as possible.

These installation rates are expected to apply to design S2a as well as to S1. Installation times for designs S2b and S3 are expected to be 33% to 50% greater than for S1.

*An LHA would have space for 500 to 800 lineal feet of breakwater of design S1 or S2a.

**The effective lengths (see Appendix E) are about 50 feet shorter than these values in a depth of water of 30 feet, and 100 feet shorter in a depth of 60 ft.

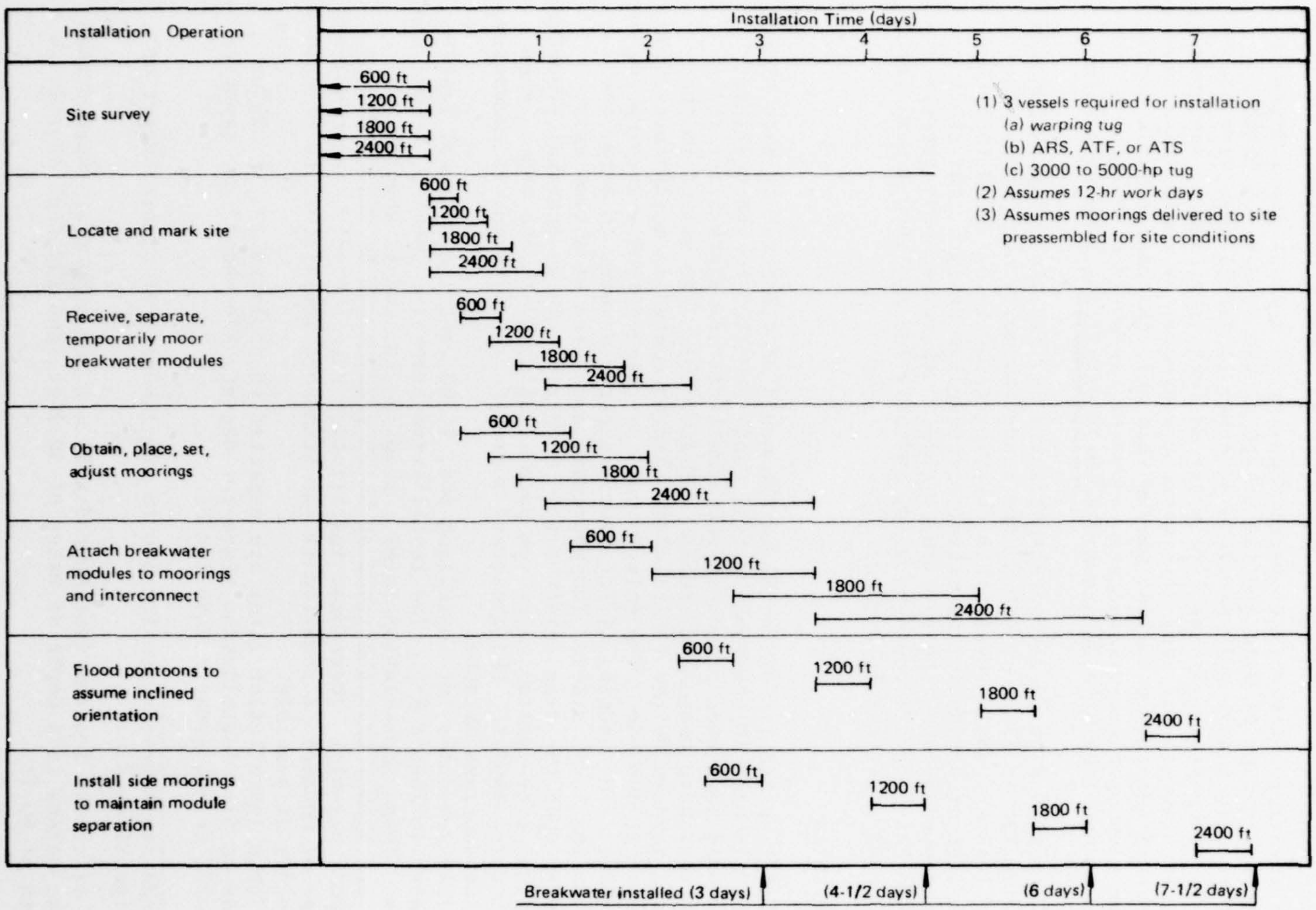


Figure F-5. Installation schedule for various lengths of sloping float breakwater (30-foot water depth).

Cost

For design S1, cost of new construction involving design modifications of 3x15 NL pontoon sections is estimated as $80,000 for one module. Moorings for a breakwater of about the minimum length of 600 feet, and for water 30 feet deep would add just over 10%. Thus, the fabricated cost is about $88,200 per float, or about $3,400 per front foot.

For designs S2 and S3, rough estimates of cost, including moorings, are $5,200 and $6,800 per front foot, respectively.

DISTRIBUTION LIST

AFB CESCH, Wright-Patterson; MAC/DET (Col. P. Thompson) Scott, IL; SAMSO/MNNF, Norton AFB CA; Stinfo Library, Offutt NE
ARMY BMDSC-RE (H. McClellan) Huntsville AL; ERADCOM Tech Supp Dir. (DELSD-L) Ft. Monmouth, NJ; Tech. Ref. Div., Fort Huachuca, AZ
ARMY CORPS OF ENGINEERS MRD-Eng. Div., Omaha NE; Seattle Dist. Library, Seattle WA
ARMY ENVIRON. HYGIENE AGCY Water Qual Div (Doner), Aberdeen Prov Ground, MD
ASST SECRETARY OF THE NAVY Spec. Assist Energy (P. Waterman), Washington DC
CINCLANT Civil Engr. Supp. Plans. Ofr Norfolk, VA
CNM NMAT 08T246 (Dieterle) Wash, DC
CNO Code NOP-964, Washington DC
COMOCEANSYSPAC SCE, Pearl Harbor HI
DEFENSE DOCUMENTATION CTR Alexandria, VA
FLTCOMBATTRACENLANT PWO, Virginia Bch VA
HEDSUPPACT PWO, Taipei, Taiwan
MARINE CORPS BASE M & R Division, Camp Lejeune NC; PWO, Camp S. D. Butler, Kawasaki Japan
MARINE CORPS HQS Code LFF-2, Washington DC
MCAS Facil. Engr. Div. Cherry Point NC; Code PWE, Kaneohe Bay HI; Code S4, Quantico VA; J. Taylor, Iwakuni Japan; PWO Kaneohe Bay HI
NAF PWO Sigonella Sicily; PWO, Atsugi Japan
NAS CO, Guantanamo Bay Cuba; Code 18700, Brunswick ME; Dir. Util. Div., Bermuda; ENS Buchholz, Pensacola, FL; PWD Maint. Div., New Orleans, Belle Chasse LA; PWO Belle Chasse, LA; PWO Chase Field Beeville, TX; PWO Key West FL; PWO, Dallas TX; PWO, Glenview IL; PWO,, Moffett Field CA; SCE Lant Fleet Norfolk, VA; SCE Norfolk, VA
NATL RESEARCH COUNCIL Naval Studies Board, Washington DC
NAVACT PWO, London UK
NAVAEROSPREGMEDCEN SCE, Pensacola FL
NAVAL FACILITY PWO, Barbados; PWO, Guam
NAVCOASTSYSLAB Library Panama City, FL
NAVCOMMAREAMSTRSTA Maint Control Div., Wahiawa, HI; PWO, Norfolk VA; PWO, Wahiawa HI; SCE Unit 1 Naples Italy
NAVCOMMSTA CO, San Miguel, R.P.; Code 401 Nea Makri, Greece; PWO, Adak AK; PWO, Exmouth, Australia; PWO, Fort Amador Canal Zone
NAVCOMMUNIT Cutler/E. Machias ME (PW Gen. For.)
NAVEDTRAPRODEVCEN Tech. Library
NAVEDUTRACEN Engr Dept (Code 42) Newport, RI
NAVENVIRHLTHCEN CO, Cincinnati, OH
NAVFAC PWO, Lewes DE
NAVFACENGCOM Code 043 Alexandria, VA; Code 044 Alexandria, VA; Code 0451 Alexandria, VA; Code 0454B Alexandria, Va; Code 04B5 Alexandria, VA; Code 101 Alexandria, VA; Code 10133 (J. Leimanis) Alexandria, VA; Code 1023 (T. Stevens) Alexandria, VA; Code 104 Alexandria, VA; Morrison Yap, Caroline Is.
NAVFACENGCOM - CHES DIV. Code 101 Wash, DC; Code 402 (R. Morony) Wash, DC; Code 405 Wash, DC; Code FPO-1SP (Dr. Lewis) Wash, DC; Code FPO-IP12 (Mr. Scola), Washington DC
NAVFACENGCOM - LANT DIV.; Code 10A, Norfolk VA; Eur. BR Deputy Dir, Naples Italy; RDT&ELO 09P2, Norfolk VA
NAVFACENGCOM - NORTH DIV. Code 1028, RDT&ELO, Philadelphia PA
NAVFACENGCOM - PAC DIV. Code 402, RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI
NAVFACENGCOM - SOUTH DIV. Code 90, RDT&ELO, Charleston SC
NAVFACENGCOM - WEST DIV. Code 04B; O9P/20; RDT&ELO Code 2011 San Bruno, CA
NAVFACENGCOM CONTRACT AROICC, Point Mugu CA; Dir, Eng. Div., Exmouth, Australia; Eng Div dir, Southwest Pac, Manila, PI; OICC, Southwest Pac, Manila, PI; OICC/ROICC, Balboa Canal Zone; ROICC AF Guam; ROICC LANT DIV., Norfolk VA; ROICC Off Point Mugu, CA; ROICC, Keflavik, Iceland
NAVMIRO OIC, Philadelphia PA
NAVOCEANSYSCEN Code 6700, San Diego, CA; Research Lib., San Diego CA; SCE (Code 6600), San Diego CA
NAVPETOFF Code 30, Alexandria VA
NAVPHIBASE CO, ACB 2 Norfolk, VA

NAVRADRECFAC PWO, Kami Seya Japan
NAVREGMEDCEN SCE (D. Kaye); SCE, Camp Pendleton CA
NAVSEC Code 6034 (Library), Washington DC
NAVSECGRUACT Facil. Off., Galeta Is. Canal Zone; PWO, Edzell Scotland; PWO, Puerto Rico; PWO, Torri Sta, Okinawa; Security Offr, Winter Harbor ME
NAVSHIPREPFAC Library, Guam
NAVSHIPYD Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA; Code 380, (Woodroff) Norfolk, Portsmouth, VA; Code 404 (LT J. Riccio), Norfolk, Portsmouth VA; Code 410, Mare Is., Vallejo CA; Code 440 Portsmouth NH; Code 440, Puget Sound, Bremerton WA; Code 440.4, Charleston SC; Library, Portsmouth NH; Tech Library, Vallejo, CA
NAVSTA CO Naval Station, Mayport FL; CO Roosevelt Roads P.R. Puerto Rico; Maint. Cont. Div., Guantanamo Bay Cuba; Maint. Div. Dir/Code 531, Rodman Canal Zone; PWO Midway Island; PWO, Keflavik Iceland; PWO, Mayport FL; SCE, Guam; SCE, Subic Bay, R.P.
NAVSUPPACT LTJG McGarrah, Vallejo CA
NAVSURFWPNCEN PWO, White Oak, Silver Spring, MD
NAVTECHTRACEN SCE, Pensacola FL
NAVWPNCEN Code 2636 (W. Bonner), China Lake CA; ROICC (Code 702), China Lake CA
NAVWPNEVALFAC Sec Offr, Kirtland AFB, NM; Technical Library, Albuquerque NM
NAVWPNSTA EARLE PW Office (Code 09C1) Yorktown, VA
NAVWPNSUPPCEN Code 09 (Boennighausen) Crane IN
NCBC CEL (CAPT N. W. Petersen), Port Hueneme, CA; CEL AOIC Port Hueneme CA; Code 156, Port Hueneme, CA
NMCB 5, Operations Dept.
NORDA Code 440 (Ocean Rsch Off) Bay St. Louis MS
NSD SCE, Subic Bay, R.P.
NTC Commander Orlando, FL
NUSC Code 131 New London, CT; Code EA123 (R.S. Munn), New London CT; Code TA131 (G. De la Cruz), New London CT
OCEANSYSLANT LT A.R. Giancola, Norfolk VA
ONR BROFF, CO Boston MA; Code 700F Arlington VA
PHIBCB 1 P&E, Coronado, CA
PMTC Code 4253-3, Point Mugu, CA; Pat. Counsel, Point Mugu CA
PWC CO Norfolk, VA; CO, Great Lakes IL; Code 116 (LTJG, A. Eckhart) Great Lakes, IL; Code 120C (Library) San Diego, CA; Code 128, Guam; Code 200, Oakland CA; Code 220 Oakland, CA; Code 220.1, Norfolk VA; Code 30C (Boettcher) San Diego, CA; Code 400, Pearl Harbor, HI; Code 680, San Diego CA; Utilities Officer, Guam; XO Oakland, CA
U.S. MERCHANT MARINE ACADEMY Kings Point, NY (Reprint Custodian)
USCG (G-ECV/61) (Burkhart) Washington, DC; G-EOE-4/61 (T. Dowd), Washington DC
USCG ACADEMY LT N. Stramandi, New London CT
USCG R&D CENTER Tech. Dir. Groton, CT
USNA PWD Engr. Div. (C. Bradford) Annapolis MD
LEHIGH UNIVERSITY Bethlehem PA (Linderman Lib. No.30, Flecksteiner)
LIBRARY OF CONGRESS WASHINGTON, DC (SCIENCES & TECH DIV)
MIT Cambridge MA; Cambridge MA (Rm 10-500, Tech. Reports, Engr. Lib.)
UNIV. NOTRE DAME Katona, Notre Dame, IN
PURDUE UNIVERSITY Lafayette, IN (CE Engr. Lib)
STANFORD UNIVERSITY Engr Lib, Stanford CA
UNIVERSITY OF ILLINOIS URBANA, IL (LIBRARY)
UNIVERSITY OF MASSACHUSETTS (Heronemus), Amherst MA CE Dept
UNIVERSITY OF NEBRASKA-LINCOLN Lincoln, NE (Ross Ice Shelf Proj.)
BECHTEL CORP. SAN FRANCISCO, CA (PHELPS)
CF BRAUN CO Du Bouchet, Murray Hill, NJ
CONCRETE TECHNOLOGY CORP. TACOMA, WA (ANDERSON)
EVALUATION ASSOC. INC KING OF PRUSSIA, PA (FEDELE)
GLIDDEN CO. STRONGSVILLE, OH (RSCH LIB)
GOULD INC. Shady Side MD (Ches. Inst. Div., W. Paul)
GRUMMAN AEROSPACE CORP. Bethpage NY (Tech. Info. Ctr)
HUGHES AIRCRAFT Culver City CA (Tech. Doc. Ctr)

NEWPORT NEWS SHIPBLDG & DRYDOCK CO. Newport News VA (Tech. Lib.)
RAND CORP. Santa Monica CA (A. Laupa)
RAYMOND INTERNATIONAL INC. E Colle Soil Tech Dept, Pennsauken, NJ
SANDIA LABORATORIES Library Div., Livermore CA
SEATECH CORP. MIAMI, FL (PERONI)
TRW SYSTEMS REDONDO BEACH, CA (DAI)
WESTINGHOUSE ELECTRIC CORP. Annapolis MD (Oceanic Div Lib, Bryan)
R.F. BESIER Old Saybrook CT
CEC Morris, Donald G., LT